April 2004 • NREL/SR-510-33893

Subcontractor Report

Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting

March 2003

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Contract No. DE-AC36-99-GO10337

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Prepared under Subcontract No. ACO-1-31042-01

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for
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EXECUTIVE SUMMARY

Corn Stover, the material remaining on the surface after the grain is collected, is the largest underutilized crop in the U.S. About 250 million dry tons, dt, is grown annually, triple the amount 50 years ago. Removing the excess after soil erosion needs are met can reduce the need to till, increase farmer income and provide 100 million dt or more for the production of fuels, chemicals and materials.

For corn stover feedstock to become a reality for large biorefineries, innovations are needed between the field and delivery to the processor in three areas:

- Collection
- Storage
- Transportation

Present studies focus on collecting and baling dry material following the grain harvest, after the stover has field dried from 60-70% moisture to less than 30%. The collection radius has typically been limited to 50 miles due to transportation cost of the bulky material. The biomass processing plant is envisaged to maintain a two week inventory on site, with bales trucked to the plant throughout the year. This system offers many areas for improvement.

To reduce collection delays and increase density, feedstock drying and densification methods are being investigated. This approach is appropriate when a dry, compacted material is desired for processes such as gasification and co-firing. However, these operations increase cost from $35/dt to $50/dt or more, and densification inhibits wet processing. Pellets need to be 'reconstituted' by soaking in water to shorten digestion time for hydrolysis—the Sugar Platform for production of fuels, chemicals and materials.

One pass harvest of both grain and stover, wet storage and rail transport to the processor appear to be advantageous, with a delivered cost of $30/dt while returning more than $30/acre net income to the farmer. The relative difference in net income between one-pass harvest and bailing to the farmer is shown in Tables A and B. One-pass nets the grower $22 to $47/ac depending on the yield. Table B, baling, nets $16 to $22/ac to the farmer for one collection site with the same collection area, 1.5 million ac with more than 1 million dt supply.

The three sites in A are connected by rail, transporting the wet material 50 miles from two collection sites to a third site, the processing plant. This system has been used successfully by the non-wood pulping industry for more than 50 years and is the focus of this study.

Table A Excess Stover Sale Net to Farmer, $/ac W/One-pass Harvest & Rail			
Basis: $30/dry ton delivered, 3-15 mi radius collection sites, 1.5 M ac			
1 dt/ac left in field	130 bu/ac	170 bu/ac	200 bu/ac
1:1 ratio, 15% moisture, sell	2 dt/ac	3 dt/ac	3.8 dt/ac
Reduced Field Operations	$ 10.00	$ 10.00	$ 10.00
P & K Nutrients ($3.20/dry ton)	(6.40)	(9.60)	(12.16)
Stover Sale, $30/dt	60.00	90.00	114.00
Total Revenue increase/ac	$ 63.60	$ 90.40	$ 111.84
Less One-pass Harvest	(16.29)	(16.29)	(16.29)
Field to Collection site transport	(10.20)	(15.30)	(19.38)
Rail from collection site, $7.50/dt	(15.00)	(22.50)	(28.50)
Net to farmer	$22	$ 36	$ 47

Removing the excess stover is expected to reduce other field operations by $10/ac. Some fields require replacement of nutrients. The P and K are valued at $3.20/ton. The N fertilizer value is more complex, dependent on crop rotation and management practices. When the stover is buried, adding 1% N fertilizer per ton of stover buried is recommended, so N use can actually increase.

Table B Excess Stover Sale Net to Farmer, $/ac W/Custom Bale & Haul			
Basis: $30/dry ton delivered, one 30 mi radius collection site, 1.5 M ac			
1 dt/ac left in field	130 bu/ac	170 bu/ac	200 bu/ac
Total Revenue Increase	$ 63.60	$ 90.40	$ 111.84
Less Custom Bale, $14.60/dt	(29.20)	(43.80)	(55.48)
Hauling, 30 mile radius, $9/dt	(18.00)	(27.00)	(34.20)
Net to farmer	$ 16	$ 20	$ 22

The actual price of stover feedstock will likely consider its ease of processing and composition value, not just the dry tons delivered. In addition, wet storage cost and yield from storage is expected to be more favorable when compared to bales based on bagasse experience. This remains to be validated for corn stover.

The one pass harvest cost is based on forage harvesting and transporting from the field to a collection center at $2.40/mile for a 10 mile average trip. Gondola cars move the wet material 100 miles from the two remote collection sites for $7.50/dt.

1. One-Pass Harvest and Sustainable Collection

One-pass stover harvest is performed now for silage, so collecting the grain and stover when the grain dries to 24% or lower and the stover is still high in moisture is feasible. Collection must be done in a sustainable manner. No-till, relatively flat fields are preferred since less is needed for erosion control. Incorporating cover crops in the rotation can also increase stover availability while improving yield, soil, water and air quality. Additional field measurements are needed to validate existing guidelines for crop practices and collection methods that balance sustainable and economic removal of surface material.

An entirely new harvester design may not be required, at least initially. The first biomass plant is expected to be operation in 2006 or 2007, with others forecasted to come on stream in 2008 to 2010. Existing collection practices can be adapted for the whole corn plant in several ways:

- Combines and Forage Harvesters

  With the large legacy of combines and forage harvesters, many will likely be modified to accommodate the new needs—probably with two discharge streams, grain and stover, while continuing to harvest soybeans, silage, hay and other crops. Increased equipment utilization and an earlier, possibly longer collection period can lower feedstock costs without shrinking custom operator margins. The forage harvester costs are well known and used in Table A. Improvements to adapt to biomass feedstock needs should lower this cost.

- Ear Corn Harvesters

  Modifying the Ear Corn Harvester head to collect and cut the stalk, blowing the leaves and other material away, while cutting the stalk into one foot billets and conveying the stalk with the ear to just one farm wagon simplifies the field logistics and facilitates separation of the components. Recovering the cob offers more "value-added" co-product opportunities. Cobs require little to no investment for stable storage. Husks may be fed to animals or combined with the stalks and trans-shipped to the collection site.

During harvest, truck traffic to supply one processing site from the field—100 or more trucks/hr— is too disruptive to be acceptable in most locations. Locating one wet stover collection site adjacent to the plant and others next to existing grain elevators and adjacent to rail lines reduces traffic. If desired, the grain can be shelled on the farm, leaving the grain and cob, further reducing congestion.

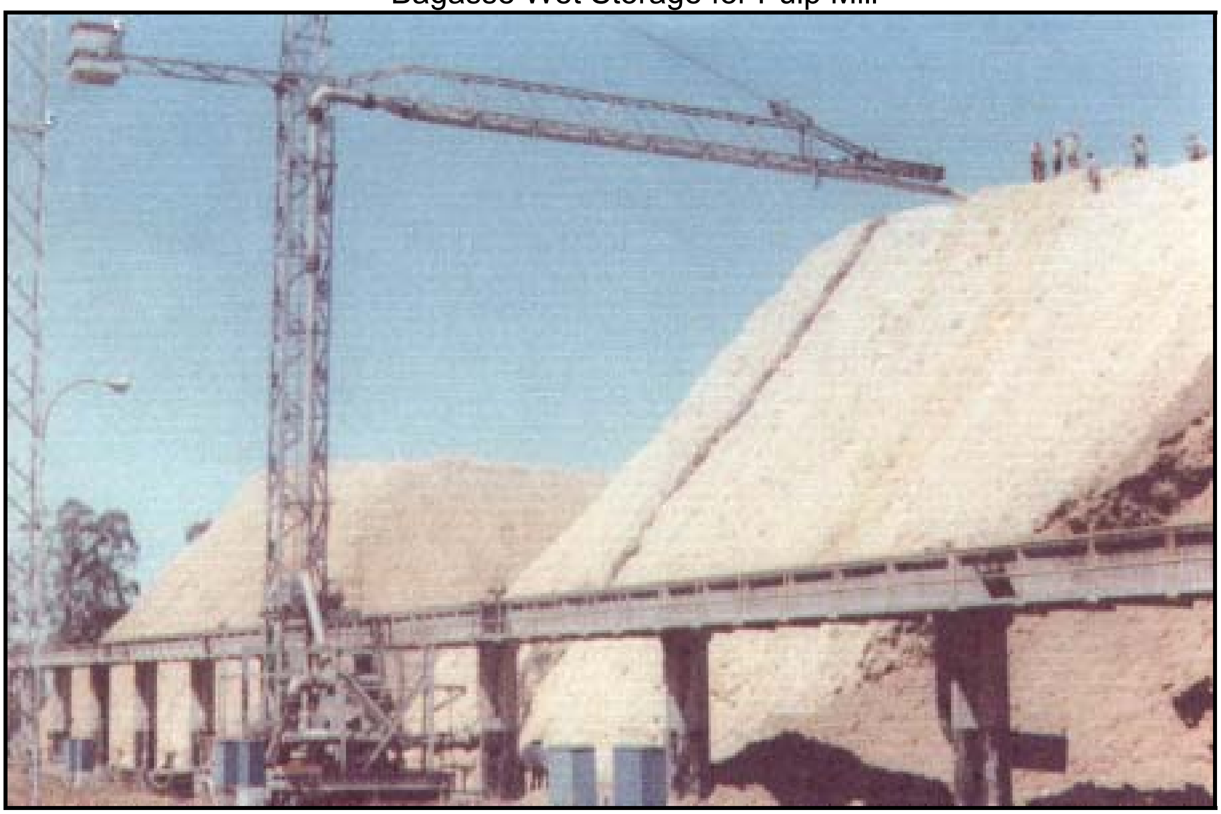
2. Storage

Wet storage, 65 to 85% moisture offers significant advantages over bales:

- 2x dry density
- Low, 3%, loss of holocellulose
- Nutrient recycled to fields
- More consistent feedstock
- Will not burn
- 10% storage area
- Removes 70% of solubles
- Reduces process ash
- Higher feedstock quality
- Fits one-pass harvest

Wet stored bagasse is proven—and has supplied pulp mills for 50 years, Figure A. Large field trials of stover are needed to validate the yield, solubles extracted and processing quality of the feedstock from wet storage process for stover. The high storage moisture raises freezing concerns in extended extreme cold spells. High moisture also limits transport options. Passing the feedstock through a screw type press can readily lower the moisture to 50% immediately prior to shipping or processing.

Figure A.
Bagasse Wet Storage for Pulp Mill



Process economics are improved with a wet, more consistent feedstock with less solubles and ash. If the solubles extracted in storage can easily recycle nutrients removed with the residue to the field, another advantage is gained over bales.

3. Transportation

Adapting wet storage and rail transport practices now used for bagasse to stover reduces traffic, increases the collection area and the economic plant size. If truck delivery is compressed to 10 hours/day six days per week, the congestion becomes intolerable for most locations, Table C.

Table C Plant Feedstock Requirements Rail and Truck Traffic Volume, units/day						
Plant, dt (000)		700	1,000	2,000	4,000	6,000
Mode	Moisture	Units/day(60 hr/week delivery)				
Rail Cars	50 to 70%	44	64	130	250	380
Trucks	50%	67 (200)	95 (280)	190 (570)	380	570
Trucks	70%	111 (333)	160 (480)	320 (1000)	640	1,000
Trucks	Bales[1]	41 (123)	60 (180)	120 (360)	240	360

[1]Bales are based on 20 tons/load, 15% moisture

Feedstock supply area can be economically expanded by locating additional collection sites for rail shipment. Transport costs 50 to 300 miles from the plant are estimated to be about $3 to $10/dt compared to $15/dt or more trucking cost.

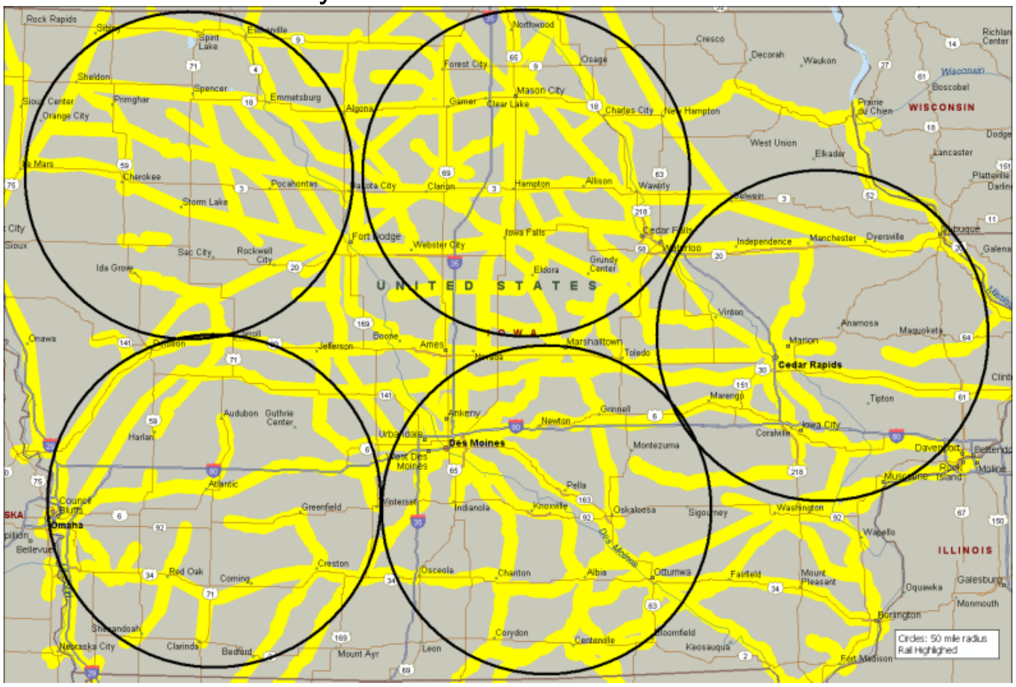
The rail cost is highly dependent on the local situation. Many miles of track have been abandoned. These may be reclaimed and place in operation. In other cases, there is local and regional service. Negotiating a win-win between the parties is needed since the material is bulky, perishable in shipment and requires reliable, economic and local processing.

Increasing plant size to from 700,000 dt to 6 million dt is estimated to lower the operating cost by 33%. Delivering 12 million dt with rail transport helps close the gap between petroleum refineries averaging over 100,000 barrels per day, Table D.

Table D Biorefinery Feedstock & Petroleum Refinery Comparison					
Plant dt/yr (000)	700	4,000	6,000	12,000	15,000
Yield, gal/dt	Ethanol Production, Barrels per Day				
80	3,800	21,800	32,700	65,300	81,600
100	4,800	27,200	40,800	81,600	102,000

The rail infrastructure is largely in place for the grain harvest. Figure C illustrates Iowa's system, most dense where the crop harvest is greatest. Traffic is seasonal. The additional rail freight possibility, 25 million dt of estimated excess stover just in Iowa, has raised much interest from both large and small rail transportation companies.

Figure C
Iowa Rail System: Circles with 50 mile Collection Radius



Conclusions

- Biorefineries with wet processes are most likely to use feedstock supplied by unit trains from wet storage collection sites well beyond the present 50 mile radius collection limit for bales
- Existing combines, forage and ear corn harvesters can be modified for one pass harvest of grain and stover
- Collection risk and cost is less for wet processes as stover is collected when grain is ready—no drying or densification is needed

Recommendations

- Develop and apply guidelines for sustainable stover removal and proceed to validate them in local areas with large amounts of excess material
- Validate wet stover storage, 75 to 85% moisture, on a scale that emulates commercial storage and determine the impact of wet storage on processing
- Prepare a revised capital investment and operating cost estimate for biorefineries using wet storage systems—from one-pass harvest and the modified cropping practices through lowering the amount of process residue and disposition cost of the residue and storage liquors
- Assess the impact on Life Cycle Analysis for stover to E85 fuels resulting from one-pass harvest, revised cropping practice, rail transport, potential nutrient return from collection sites and plant processing factors
- Prepare a "Big Picture" plan for implementation with wide participation of members in the supply chain and related stakeholders

1. Introduction

Corn Stover, the material remaining on the surface after the grain is collected, is the largest underutilized crop in the US. About 250 million dry tons, dt, is grown annually, triple the amount 50 years ago. Removing the excess amount after soil erosion and quality needs are met can reduce the need to till, increase farmer income and provide 100 million dt or more feedstock for the production of fuels, chemicals and materials. Inclusion of cover crops in the crop rotation can improve soil, water and air quality while making more stover available.

For corn stover feedstock to become a reality for large biorefineries, innovations are needed between the field and delivery to the processor in three general areas:

1.1. Collection
1.2. Storage
1.3. Transportation

Present corn stover methods have focused on collecting and baling dry material following the grain harvest. The biomass processing plant is envisaged to maintain a 10 to 20 day inventory on site, with bales supplied to the plant throughout the year. The collection radius has typically been limited to 50 miles due to transportation cost of the bulky material. This system offers many areas for improvement.

To reduce collection delays and increase density, feedstock drying and densification methods are being investigated (Mani et. al., 2002; Sokhansanj and Turhollow, 2002). This approach appears appropriate when a dry, compacted material is desired for processes, such as gasification and co-firing.

However, these operations add cost to the present delivered cost, \$35 to \$50/dt (Glassner et. al., 1998; Hettenhaus and Schechinger, 2000; Perlack and Turhollow, 2002). Increasing density from 8 to 20 lbs/ft^3 (120 to 500 kg/m^3) adds about \$15/dt. Drying from 45% moisture to 10% can add another \$15, increasing delivered cost to the processor to more than \$60/dt in a 50 mile radius.

For wet processes—hydrolysis and fermentation—one-pass harvest of both grain and stover, wet storage and rail transport to the processor appear to be advantageous, with a delivered cost less than \$30/dt while returning more than \$30/ac income to the farmer. This method has been successfully used by the non-wood fiber pulping industry for more than 50 years and is the focus of this study.

1.1. Collection—Move to One-Pass Collection

Recent stover collection trials of several acres describe the difficulties encountered by others—particularly dirt, low yields, short harvest window and low bulk density (Billy, 2000; Montross et al, 2002). Corn stover has been collected on a large scale the past five years for commercial purposes around Harlan, IA. That experience,

along with similar operations in Wisconsin and Illinois are described in detail, along with desired improvements (Hettenhaus and Schechinger, 1999, 2000).

While foreign material, soil compaction, storage conditions, fire, cost and other factors are important issues, the most serious collection risk is a wet harvest season that jeopardizes collection of the required feedstock. When the corn grain dries to 24% moisture, the combine can harvest it without damaging the kernels. The heterogeneous stover moisture is 20% to 75% at the grain harvest time, with the stalk being highest (Myers and Underwood, 1992), Table 1.

Table 1
Corn Stover Material Distribution
Dry Matter During Grain Harvest

Stover Component	Moisture %	Stover %, dry basis
Stalk	70-75	50
Leaf	20-25	20
Cob	50-55	20
Husk	45-50	10

For baling, stover must remain in the field three days or more to get below 30%, preferably 20%, to avoid damage in storage. Wet weather can increase collection cost and delay baling interminably.

In 1997, nearly 50,000 dt of stover were collected from 30,000 acres (12,000 ha) in a 50 mile radius near Harlan, IA to supply a furfural plant. An early ice storm in October curtailed the harvest.

Still, this stover harvest is considered a success compared to earlier efforts. The $35/dt delivered price was attractive to more than 400 farmers and 30 contract balers that signed on, with hundreds of farmers and dozens of contractors on the waiting list.

Based on the Harlan area experience, at least 15 times this amount, 700,000 dt, is required as feedstock for the smallest economically sized biorefinery. Commitments from more than 4,000 farmers are likely needed to supply 700,000 dt. In addition, about 250 to 300 baler crews are required.

To successfully manage this baling effort during the short harvest window for stover is a huge and risky undertaking. The logistics to dispatch baling crews to “ready” fields is difficult to manage: “What fields are ready?” asks the dispatcher and “Where do we go next?” asks the baler crew and the bale haulers, “When is the field going to be cleared?” asks the farmer. Wet weather delays that idle the baling crews can make costs prohibitive and jeopardize feedstock supply for the plant. One-pass collection of both grain and stover obviates many of these concerns.

1.2. Storage: The Past is Prologue

In the early 1920's the sugar cane industry investigated ways to store bagasse for processing to particleboard and pulp. Bagasse is the sugar cane fiber remaining after the sucrose is extracted. It typically exits the process at 50% moisture. Some is burned for process energy. Economic disposition of the remainder became a priority as boiler efficiency improved.

Celotex Corporation explored many storage methods for bagasse in Louisiana, as well as corn stover and other agricultural fibers in the 1920s and 1930s. The first patent (Lathrop and Munroe, 1926) claimed that one of two conditions must exist during storage for good fiber properties and minimum storage losses:

- The moisture content must be below 20% during storage so that the microbial activity is nearly dormant OR

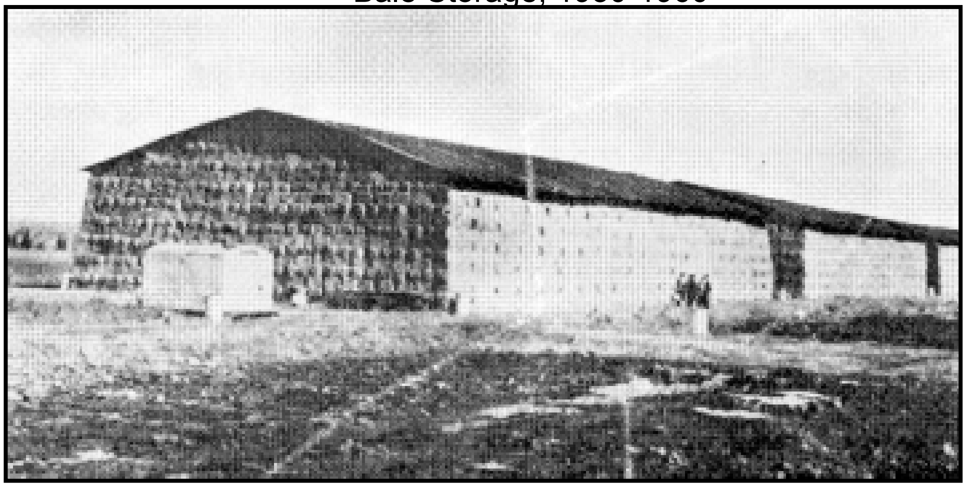
- The material must be kept wet, near its maximum water holding capacity of about 80% moisture

1.2.1. Dry Storage

Celotex produced insulation board, a dry process, and pursued ways to improve dry feedstock storage. This effort resulted in another key patent for using the heat from microbial fermentation to dry bales from 50% to less than 20% moisture (Munroe and Lathrop, 1933). The bales were sized and stacked to dissipate heat and acid fumes without fiber damage. Sheltered from the weather, bales kept for several years without serious deterioration or fiber loss. The method is described in several papers (Lathrop and Munroe, 1934; Hay and Lathrop, 1941). Classical Celotex bale storage is pictured in Figures 1.1 and 1.2

Figure 1.1
Bale Stacking, circa 1930

Figure 1.2
Bale Storage, 1930-1960



This dry storage method was used for more than 40 years. However, a change to wet storage occurred in the 1960's due to increasing recognition of its disadvantages, including the following:

- The bales were relatively small, weighing 250 lbs (115 kg) ‘as is’
- Mechanical handling was slow and costly
- The bales had to be precisely stacked to vent fumes and dissipate heat
- Procedures were labor intensive
- Several months were required to dry bales from 50 to 20% moisture
- Fire loss and increasing fire insurance costs

While some progress in handling has occurred, recent experience in baling, storing and transporting has demonstrated the issues above are still valid today. Corn stover bales harvested in 1997 for furfural feedstock are shown in Figure 2.1 to 2.4.

Figure 2.1
Bale Storage, ’97 Winter

Consistent, dense bales and covered storage on well-drained pads can minimize the feedstock loss. Outside storage, even with wrapped bales, results in higher loss, as shown in the summer pictures of the same pile.

Figure 2.2
Round Bale Loss

Figure 2.3
Square Bale Loss

Other hazards remain—like fire. Once ignited, bale fires cannot be extinguished. Figure 2.4 shows the results from a fire in Harlan, IA started when a small flame caused by a welder's spark blew into the stacks on a windy day. The blaze destroyed much of the inventory shown in Figure 2.1, burning for several weeks.

Figure 2.4
Storage Area After Bale Fire

1.2.2. Wet Storage

While Celotex pursued dry storage, other companies in the pulp and paper industry continued investigating wet storage of non-wood fibers for feedstock since pulping is a wet process. The results were more successful than dry storage. Even companies with a dry process like Celotex abandoned bales in favor of wet storage. Wet storage of bagasse has been in wide use on a commercial scale since 1960.

There are usually three wet storage piles—one supplying the process, another being built, and a third "aging" feedstock before pulping. Three months or more of wet storage removes most of the solubles, reduces the variation in composition and results in a more consistent feedstock with less ash supplied to the processing plant.

Figure 3.1
Wet Storage Pile Construction

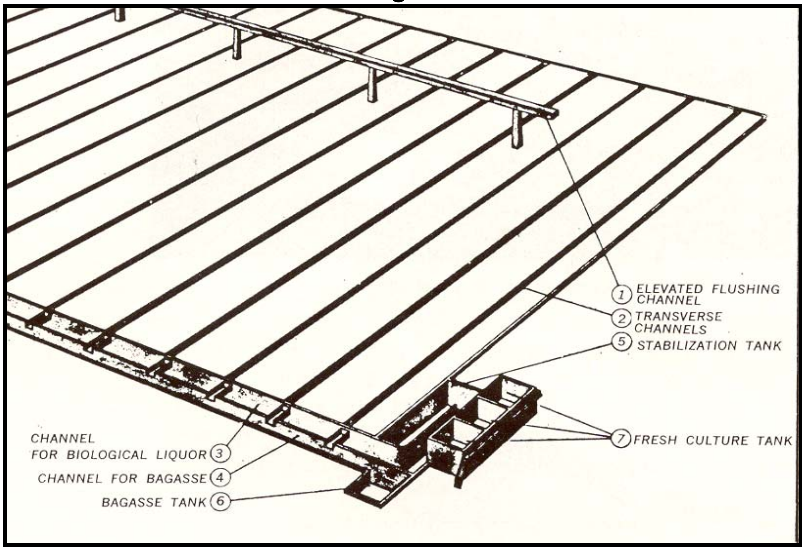
Figure 3.1 shows a typical collection area with a pile under construction in the foreground. Preservation is exceptional, with 1 to 3 % of cellulose and hemicellulose loss during extended storage, Figure 3.2 and 3.3.

Figure 3.2
Storage after 18 months

Figure 3.3
Close-up, 18 month bagasse

Unlike ensiling forage for animal feed, the material is typically slurried to 3% solids and piped to a storage pad, 200 meters x 300 meters or more, Figure 4.

Figure 4
Ritter Storage Drain Pad



The liquor drains through the pile, and is recirculated until a height of 20 to 40 meters is reached. There are many benefits of wet storage when compared to bale storage methods. The major advantages include:

- 2x bulk density
- 10x less storage area
- Stable, safe storage—will not burn
- No baling cost
- No wrap disposal for round bales
- Removes dirt and solubles, less process ash, more process capacity
- Potentially recycle the nutrients in the stover to the fields

Adapting wet storage to corn stover fits well with corn stover harvest, avoiding the need for stover to remain in the field to dry. Simultaneously harvesting both the grain and the excess stover can reduce the weather risk and soil compaction in addition to lowering cost.

1.3. Transportation

Transportation of bales and the related logistics is complex. Supplying the processing plant 2,000 dt/day during the year requires about 100 deliveries per day, 20 trucks per hour in and out, 350 days per year. If the delivery schedule is compressed to six-10 hour days, traffic increases to 100/hour or more. During harvest, the volume of traffic is more disruptive, depending on collection sites and baling crew movements. Figure 5.1 shows square bales loaded for highway transport: a load-and-go wagon pulled by a high speed (50 MPH) JCB tractor and a conventional truck with a loaded wagon.

Figure 5.1
Bale Transportation Modes

An errant spark ignited a wagon of bales in transit during the ’97 Harlan harvest. The driver parked the rig in a rural area, limiting the fire damage to just the bales and wagon. The possibility of similar incidents in a populated area or shipping bales via rail raises serious safety concerns. Liability insurance for large operations will likely be required, along with other precautions for shipping the flammable cargo.

The Pulp and Paper Industry use a wide variety of transport options. For bulky wet fibers like bagasse, rail is preferred (Williams, 1970). Gondola rail cars have long been used to economically collect wet bagasse from small sugar mills to supply feedstock for non-wood fiber pulp mills, Figure 5.2.

With a hauling capacity of 100 tons, just 50 to 70 cars can meet the 2,000 dt/day needs, greatly reducing the logistics and congestion from trucks.

Figure 5.2 Covered Gondola Car

2. Stover Collection—Sustainable Removal

Some surface cover is required for erosion control. The amount is determined using models developed by the USDA—RUSLE and WEQ—for water and wind erosion respectively. Collecting excess stover only from "no-till" fields is recommended. Tilling causes loss of soil organic material, SOM, an important measure of soil quality. If too much stover is removed or a cover crop is not planted, SOM can be depleted. Studies at the National Soil Tilth Laboratory (Cambardella and Gale, 1999) shows 80% or more of the surface material is lost as CO_2 within months, and 3x the amount of SOM comes from roots compared to surface material.

In contrast, 6 tons of stover are required to maintain SOM with conventional tilling practices (Larson et. al., 1972; Clapp et. al., 2000). Tilling also complicates stover collection logistics, since the farmer usually wants to get back in the field to complete fall operations.

To summarize the previous studies, stover is now harvested with either round or square balers following the grain harvest. During harvest, some stover is knocked to the ground, run over by the combine, trucks and farm wagons. As much as 50% to 70% can be lost due to field and baling losses (Billy, 2000; Montross et. al., 2002; Pordesimo et. al., 2002, Perlack and Turhollow, 2002). The stover that is knocked down and then picked off the surface brings along with it much dirt. In addition, baling operations can result in additional soil compaction—never desirable, especially in no-till fields.

2.1. Collection Improvements

One-pass harvest offers significant improvements in collection. Stalk moisture is no longer a constraint. The stover can be collected when the grain is mature and dry enough to harvest. Fewer field operations simplify logistics. With some harvesting methods, the stover never touches the ground. Less loss in the field occurs and dirt and foreign material in the stover is reduced.

2.1.1. Excess Removal

Initially, no-till fields with a history of good moisture, high yields, slopes less than 6% and in corn and soybean rotation will attract attention for stover harvest. Crop moisture needs limit stover removal in some areas, especially west of the Missouri river (Doran, 1984; Power, 1986; Wilhelm, 1986). For areas further east with more moisture, especially in the northern part of the Corn Belt, NOT removing stover from no-till fields reduces yield due to cold wet soils in the spring (Linden et. al., 2000)

Table 2 estimates the range of excess stover that is available for varying yields and conditions for erosion control. Applying the USDA soil erosion models to each field for helping to determine the excess stover that can be removed and stay well within the guidelines for best management practices will be *de rigueur*.

Table 2
Erosion Protection Needs
Estimated Stover Availability, dt/ac
No-till Fields

Yield, bu/ac	130	170	200
Stover Produced, assume 1:1 grain	3.1	4.0	4.8
Stover Available			
USDA Model Results	0 to 2.6	0 to 3.6	0 to 4.3
Model results w/fall cover crop	3.0	3.8	4.6
70% removal, leave 6" anchored stubble and leaves,< 6% slope	2.2	2.8	3.3

Conservation tilled fields further reduce the amount available. Cover crops can provide better erosion protection. They are also beneficial for improving soil, water and air quality and reducing N fertilizer inputs.

The USDA models are based on the weight of the material remaining on the surface, yet surface cover is a key condition for erosion protection. Leaves and husks have more surface area per pound than stalks and cobs, but may blow away. They also decay faster than stalks and cobs, so some model refinement will likely occur. Additional local studies that consider narrow rows, direct seeding and other parameters that reflect changes in crop properties, rotation and management practices can validate the database for the models

Controlling the amount of stover removed is difficult with present baling practices. Harvesting the whole corn plant may provide better control of stover components left in the field. Leaves and possibly the husks can be left for surface cover if they remain in the field. Stalk height can be adjusted as a windbreak.

To prevent water erosion the leaves and husks, 20% and 10% of the stover mass, but with much area, may be left to protect the soil surface from the kinetic energy of the raindrops. Narrow rows, 15 to 20 inches, help trap the husks and leaves, better

preventing them from being blown away than 30 inch rows. Narrow rows also provide an early canopy to reduce moisture loss and diurnal temperature variation.

Anchored stubble provides good wind protection. In the Eastern and Midwestern Corn Belt the stubble is often enough protection for no-till fields . The stalk can be cut at the best height required for soil protection from wind erosion—about 6 inches above the crown. The remainder of the stalk and the ear is removed from the field.

2.1.2. One-pass Harvesting Methods

One-pass harvest studies are currently underway by Universities, National Laboratories and Ag Machinery Suppliers to evaluate adapting existing systems and developing new designs for harvesting stover and straw (Quicke and Tuetken, 2002; Hess et al., 2002; St. George, 2002; Thompson et. al., 2002). Some envision one harvest port coming from the harvester, separating the stalk from the ear off-site. Others see two separate discharges from the combine—one with the grain, the other with the stover. Combinatorial choices include:

- One or two combine discharge streams
- Deliver in one truck w/stover and ears OR two trucks for 2 combine discharges
- Entire plant, leaving crown OR Stover w/o leaves + Ear OR Stalks + Grain
- Separate grain in field OR farm OR at collection center

An interim report (PAMI, 1998) modeled five systems for a 1,000 acre wheat crop. Revenues were based on 30 bu/ac wheat, with a grain, chaff and straw valued at \$35/dt and wheat at \$3.81/bu. The whole crop baling case has the lowest cost and highest value. The model assumed the crop would be swathed, baled and hauled 5 miles for threshing. The straw would not be rebaled. The results are summarized in Table 3.

Table 3
Comparing Whole Crop Harvesting Systems for Wheat

SYSTEM	Operation Cost, \$/ac	Net Harvest Value \$/ac
Windrow Combine	\$ 50	\$ 88
Straight Cut	\$ 39	\$ 95
Stripper Harvest	\$ 35	\$ 95
McLeod Harvest	\$ 33	\$ 101
Whole Crop Baling	\$ 28	\$ 112

In a stover study, two harvest scenarios were investigated in a field trial October 2001 near Harlan, Iowa. Fields with 150 bu/ac corn were harvested, collecting the stover discharged from the rear of the combine. A Stakhand compacted the stover and left the pile in the field in the first trial. The second trial used a caddy with a forage blower to load a separate farm wagon directly (Quicke and Tuetken, 2002).

Excluding the lost productivity due to low power, the cost for the combine-stacker system was \$9.59/ac and \$3.83/dt stover for 150 bu/ac. The combine-caddy system was \$10.05/ac and \$4.42/dt stover. A previous study adapting a forage harvester using 210 bu/ac estimated the cost to be \$3.16/dt. The value is identical with the

combine-caddy system, \$4.42/dt when prorated to 150 bu/ac yield for 400 hrs annual use, 4.5 ac/hr (Turhollow et. al. 1996). Transportation from the field is not included in either case. All assumed 70% collection efficiency.

2.1.3. One-pass Corn Harvest Cost

There are three issues considered for one-pass harvest: Whole crop harvest, transport to the collection center and the growers benefit from the sale of the stover.

<u>Whole Crop Harvest</u>

While the above trials are indicative of the savings, the forage harvester is the only method now commercially available for one-pass corn harvest. It removes the whole plant and cuts it into small pieces for ensiling. The harvesting costs are well known for various models. They can be pulled with a tractor or are self-propelled. The operating cost for a self-propelled unit is shown in Table 4 (Schnitkey et. al., 2000). It has a 6 row corn head, requires 365 HP and lists for \$214,000.

Table 4
Corn Silage Forage Harvesting
Operation cost per acre

Acres	Fixed Cost	Fuel & Lube	Labor	*Cost per Acre*
600	\$ 27.98	\$ 6.20	\$ 3.10	*\$ 37.28*
900	\$ 18.65	\$ 6.20	\$ 3.10	*\$ 27.95*
1,200	\$ 13.99	\$ 6.20	\$ 3.10	*\$ 23.29*
2,400	\$ 6.99	\$ 6.20	\$ 3.10	*\$ 16.29*

The earlier evaluation (Turhollow et. al., 1996) estimated the operating cost to be identical for a 400 HP self-propelled forage harvester. The same rate, 4.5 ac/hr, was used with a collection efficiency of 70%. Table 5 summarizes the harvest cost as a function of harvester utilization and yield from Schnitkey's analysis in 2000. For large operators, harvesting 2,400 acres during 44 twelve-hour days, the cost is \$2.06/dt for 200 bu/ac and \$3.17/dt for 130 bu/ac. Later cost examples assume 2,400 ac.

Table 5
Harvest Cost for Forage Harvester

	Harvest Cost, \$/ac			Harvest Cost, \$/dt @ 70% eff			Operating
Acres	Fixed Cost	Direct Cost	Total Cost	130 bu/ac	170 bu/ac	200 bu/ac	Days, 12 h/day
900	\$18.65	\$ 9.30	\$ 27.95	\$ 5.44	\$ 4.16	\$ 3.54	17
1,200	\$13.99	\$ 9.30	\$ 23.29	\$ 4.53	\$ 3.47	\$ 2.95	22
1,800	\$ 9.33	\$ 9.30	\$ 18.63	\$ 3.63	\$ 2.77	\$ 2.36	33
2,400	\$ 6.99	\$ 9.30	\$ 16.29	\$ 3.17	\$ 2.43	\$ 2.06	44
3,600	\$ 4.66	\$ 9.30	\$ 13.96	\$ 2.72	\$ 2.08	\$ 1.77	67

The forage harvester may be more expensive than needed for lignocellulosic feedstock. The knives now employed to reduce the plant to silage cut the plant into 0.35” (9mm) pieces for storage and later animal consumption. Just cutting the stalk to 1’ (300mm) pieces in the field reduces the power needed in the field equipment especially if the leaves and husks are left in the field, uncut.

For stover processing, the stationary mill uses 2 HP per ton to shred the feedstock for wet storage. Hammer mills used for dry material milling require about 2x more power (Atchison and Hettenhaus, 2002). The outlook for improving collection costs is encouraging. If 20% of the field power is reduced, the cost drops about $1/ac, from $6.20/ac to $5.00/ac fuel and lube value (Table 4).

Adding knives to cut stalks into 1’ billets to the Ear Corn Harvester after the ear is removed and conveying both into the hopper for transfer to the farm wagon modifies it to a one-pass harvester, Figure 6. Picking ear corn is about $30/ac for a 6 to 8 row head when used for 800 ac/year, slightly less than a forage harvester (Ahrens, 2002). The shelling cost off the field needs to be considered, balanced with the disposition of the cobs and husks.

Figure 6, Ear Corn Harvester

Separation of components—ears and stover, then leaves, billets, husks, grain and cobs, is facilitated with this unit. Cobs may offer value added opportunities.
The harvested grain yield may be higher with less broken kernels and foreign matter when using an ear corn harvester than a combine or forage harvester. A combine varies in grain collection efficiency and grain damage with changes in grain moisture, throughput, and interactive combine adjustments. Detailed measurements shows collection efficiency varies between 90 and 100%, with breakage varying between 1 to 9% (Columbus et. al., 2000; Mowitz, 2001; Quicke, 2002; Melvin, 2002).

Recent combine models perform with high efficiency and cause little kernel damage, but maladjustment can easily exceed $3.00/ac when the combine is out of adjustment or older models are used. The potential cost for each % loss in harvest efficiency and broken kernels and foreign matter, BKFM, is shown in Table 6. The usual penalty for BKFM is minus $0.02/bu for each 1% from 3.1% to 5.0%, minus $0.03/bu for each 1% from 5.1% to 7.0%. Over 7.0% BKFM is subject to rejection.

Table 6
Combine Maladjustment cost per Acre, $2.30/bu corn

	Change	130 bu/ac	150 bu/ac	170 bu/ac
Harvest loss	1%	$ 2.99	$ 3.45	$ 3.91
BKFM >3.1 %	1%	$ 2.60	$ 3.00	$ 3.40

Load density and volumes from the ear corn harvester fit current practice. Ear corn is 22 to 28 lbs/ft^3 (Campbell, 2002). Billets and ears are 15 to 20 lbs/ft^3, readily transported with existing equipment and road load limits. For hauling, farm wagons with 2,700 ft^3 reach both load and volume limits at 15 lbs/ft^3, standard 40’ trailers, 3,000 ft^3, max at 13 lbs/ft^3 and 48’ trailers at 11 lbs/ft^3.

Transport Cost from Field to Collection Center

The cost of transporting farm wagons or over-the-road trailers from the field to the collection center is normally based on collecting within a 50 mile radius of the plant. The large area balances transportation cost with participation and weather risk. With one-pass harvest and high moisture stover, the transport cost quickly increases as

shown in Table 7. The values assume collecting 70% of the stover, 2.8 dt/ac, from 40% of the land within the radius.

Table 7 Availability and Truck Transport Cost of Wet Stover					
Collection Radius Mi	Collection Area Ac (000)	Collected dt (000) 40% Ac	Roundtrip avg miles	$2.40/mi, 10 dt/trip $/trip	$/dt
10	201	225	14	$ 34	$ 3.40
15	452	507	21	$ 51	$ 5.10
30	1,810	2,030	42	$ 102	$ 10.20
40	3,217	3,600	57	$ 136	$ 13.50
50	5,027	5,630	71	$ 170	$ 17.00

The results show multiple collection sites may be more economic for one-pass collection in a 15 mile radius when stover can be transshipped miles by rail for less than $10.00/dt, Table 7 ($17.00/dt for 50 miles vs $5.10 + $10.00 for 15 miles and rail trans-shipment). Three collection sites each with a 15 mile radius can supply more than 1 million dt feedstock (3 x 507,000 dt) for a transport cost less than collection in a single 50 mile radius. The collection and rail transport costs are further described in *3. Collection* and *4. Transportation.*

Farmers Benefit

Improving the rural economy is given as a driver for using stover and other biomass. How will the farmers with excess stover benefit? Some in the northern part of the Corn Belt with cold wet soils and/ or excessive amount of stover see selling the excess as a way to reduce field operations and related cost. Many indicate net income from the sale needs to be in the range of $20 to $40/ac, $10/dt or more. Any out-of pocket cost for removing stover must be reimbursed when incurred, while the remainder may be applied to equity in a proven process.

Since it is bulky to ship, a long term, win-win relationship is needed between the supplier and the processor to insure local, reliable and economic feedstock. Recognizing this, Kearney Area Producers Alliance, Central Illinois Fibers Association and other grower organizations see the potential feedstock as a way to move into the value chain when used to produce fuels, chemicals and materials.

All generally agree that one-pass harvest is preferred to baling to reduce cost, compaction and related logistics. Table 8.1 and 8.2 compare the net farmer income for the two cases, using a delivered price of $30/dt within a 30 mile radius. The calculations show one-pass harvest provides $6 to $25/ac more farmer income than baling, depending on the yield.

Table 8.1 Excess Stover Sale Net to Farmer, $/ac W/One-pass Harvest & Rail			
Basis: $30/dry ton delivered, 3-15 mi radius collection sites, 1.5 M ac			
1 dt/ac left in field	130 bu/ac	170 bu/ac	200 bu/ac
1:1 ratio, 15% moisture, sell	2 dt/ac	3 dt/ac	3.8 dt/ac
P & K Nutrients ($3.20/dry ton)	$ (6.40)	$ (9.60)	$ (12.16)
Reduced Field Operations	10.00	10.00	10.00
Stover Sale, $30/dt	60.00	90.00	114.00
Total Revenue increase	$ 63.60	$ 90.40	$ 111.84
Less One-pass Harvest	(16.29)	(16.29)	(16.29)
Field to Collection site transport	(10.20)	(15.30)	(19.38)
Rail from collection site, $7.50/dt	(15.00)	(22.50)	(28.50)
Net to farmer	$22	$ 36	$ 47

Table 8.2 Excess Stover Sale Net to Farmer, $/ac W/Custom Bale & Haul			
Basis: $30/dry ton delivered, one 30 mi radius collection site, 1.5 M ac			
1 dt/ac left in field	130 bu/ac	170 bu/ac	200 bu/ac
1:1 ratio, 15% moisture, sell	2 dt/ac	3 dt/ac	3.8 dt/ac
P & K Nutrient credit ($3.20/dry ton)	$ (6.40)	$ (9.60)	$ (12.16)
Reduced Field Operations	10.00	10.00	10.00
Stover Sale, $30/dt	60.00	90.00	114.00
Total Revenue Increase	$ 63.60	$ 90.40	$ 111.84
Less Custom Bale, $14.60/dt	(29.20)	(43.80)	(55.48)
Hauling, 30 mile radius, $9/dt	(18.00)	(27.00)	(34.20)
Net to farmer	$ 16	$ 20	$ 22

The stover price in the example is based on “dry tons.” The actual price will likely consider the composition value of the feedstock, especially its cellulosic material, and its ease of processing. In addition, the loss in storage, the storage cost, and impact on plant site feedstock handling are important economic factors. All favor wet feedstock based on bagasse experience, but remain to be quantified for corn stover. For bagasse, wet storage incurs less loss than bales and provides a higher quality feedstock, discussed further in *3. Storage.*

2.1.4. Increased Tonnage from Field

Regardless of the field collection method, the tonnage harvested increases 2x to 4x, even if the leaves and husks, 30% of the stover dry mass (Table 1), are left. If all except the anchored stubble above the crown were removed from a 200 bu/ac field, total tonnage increases from 5 tons/ac of grain to 20 tons/ac of grain and stover.

Using a 1:1 ratio of stover to corn, harvesting just the stalk and cob at 60% moisture results in removing 9 to 10 tons/ac for 130 bu yield:

- Field Harvest, 130 bu/ac, grain and 70% of stover
  - 130 bu/ac * 56 lbs/bu @ 20% moisture = 3.9 tons /ac grain
  - 0.7*130bu/ac * 56 (0.845/0.4) @ 60% moisture = 5.4 tons/ac stover

For 200 bu/ac, 14 ton/ac is removed. Leaving anchored stubble increases the harvest to 20 tons/ac, including the grain. Compared to sugar cane and potato harvest, 35 to 40 tons/ac, the quantity is relatively small.

If the grain is not separated during the harvest or on the farm, 2.6 to 3 million tons must be transported for a 700,000 dt stover plant for separation. Removing the grain prior to transporting to the collection site reduces the quantity 40%. The cases are presented below.

- Stover transport with grain: 2.6 to 3 million tons, depending on cover left in field
  - 70% stover, husks and leaves left for cover, 3 million tons of stalk, cobs, corn grain transported

    700,000 dt (1.4/0.8 corn grain + 1/0.4 stover) = 3 million tons

  - 80% stover, leaves left for cover, 2.7 million tons of stalk, cobs, husks, corn grain transported

    700,000 dt (1.1/0.8 corn grain + 1/0.4 stover) = 2.7 million tons

  - Anchored Stubble, 2.6 million tons of leaves, stalk, cobs, husks and corn grain transported

    700,000 dt (1/0.8 corn + 1/0.4 stover) = 2.6 million tons

- Stover transport only—no grain, 1.8 million tons stover

    700,000 dt (1/0.4 stover) = 1.8 million tons

The resulting traffic during harvest raises a significant concern. Bales may be stacked and left on the farm, but wet stover needs to be transported to a collection site, washed, shredded and conveyed to a drainage pad for storage.

2.2. Harvest Logistic Models

Logistics of sugar cane and potato harvest offer potential models that may be adapted to stover harvest. Both have higher tonnage than harvesting the whole corn plant—30 to 40 tons/ac vs 20 tons for corn—and a long harvest history in the US. Delivery is exclusively "over the road" in the US. Rail is used in other countries. Sugar cane is perishable, about 24 hours can elapse between cutting the cane and processing before fermentation begins to reduce yield. Potatoes are more stable, but both cane and potatoes spoil quickly when frozen—always a risk late in the harvest season.

2.2.1. Sugar Cane—A model for delivery and preparing for storage

Two cases are described based on US sugar cane practices. Case 1 reflects the present practice for sugar cane and the conditions if grain and stover are delivered to a collection site at 45% moisture. Case 2 represents wet harvest conditions, 60% moisture, when just the stover is delivered to the site and the grain is separated and stored elsewhere.

For Case 1, a large Louisiana sugar mill is the model. Truck delivery time for perishable sugar cane is scheduled months in advance. Deliveries average 17,000 tons per day, t/d. The high is 24,000 t/d. Cane moisture is typically 45%. Stover can be 60% or 70% moisture. The total tons delivered over 60, 75 and 90 days for 17, 20 and 23 thousand t/d are shown in Table 9.1.

Table 9.1
Case 1 Delivery Model
Sugar Cane Mill
Dry tons and *"as is" tons,*

Delivery	45% Moisture Delivered Tons "as is" (000)		
Daily Avg	*17*	*20*	*23*
Days	Total Dry Tons/*"as-is" tons* (000)		
60	560/*860*	660/*1,020*	***760/1,170***
75	***700/1,080***	***825/1,270***	***950/1,460***
90	***840/1,300***	***990/1,520***	***1,140/1,752***

The delivery days required to supply a 2,000 dt/d biorefinery, 700,000 dt annually over 60 to 90 days are in bold print:

- 90 days meet the needs for all daily averages
- 60 days works for 23,000 tons/day average delivery
- 75 days provide more margin, ranging from 700,000 to 950,000 dt with average delivery from 17,000 to 23,000 tons "as is" at 45% moisture.

During a wet harvest season, the stover may be as high as 60% when harvested, and is taken as Case 2. Table 9.2. A wet harvest season requires 90 days and the

delivered tons “as-is” tons exceeds cane delivery experience—not an encouraging result to take forward.

Table 9.2 Case 2 Delivery Model Sugar Cane Mill Dry tons and *”as is” tons*			
Delivery	60% Moisture Delivered Tons “as is” (000)		
Daily Avg	*17*	*20*	*23*
Days	Total Dry Tons/*”as-is” tons* (000)		
75	510/*1,275*	600/*1,500*	690/*1,725*
90	612/*1,530*	***720/1,800***	***828/2,070***

The unloading is efficient, developed over more than a century of operation. Dual trailer unloading stations result in rapid truck unloading. The plant can unload up to 100 trucks per hour, 5 minutes per unloading cycle, Figure 7.

Figure 7
One of Five Cane Unloading Stations

Conveyors move the cane (mostly stalks for stover) to the cane washing and shredding line. Since sucrose is highest at the bottom of the stalk, cane is harvested at ground level. As a result, the extraneous matter—mostly dirt—is high, 6 to 7 %.

The cane billets are washed to remove the dirt using a counter current washing process. The washed feedstock is drained across a screen and then shredded, using a hammer mill, so the sugar extraction is facilitated. Small particle size also insures tight compaction for stable bagasse storage. The wash water is centrifugally cleaned and recycled. The dirt is returned to an adjacent field, along with the circulating liquid at the end of the harvest season. The process line is shown in Figures 8, 9 and 10.

Figure 8
Cane in Conveyor Feed Pit

Cane is typically cut into 1’ (300 mm) lengths to ease handling and processing.

Figure 9
Take-Away Conveyor

Figure 10
Cane Process Line

Drum washers, screens and magnets remove the dirt and other foreign material from the biomass before it is shredded in a large hammer mill and, after sugar extraction, conveyed to storage, Figures 11, 12, 13 and 14.

Figure 11
Cane Washer

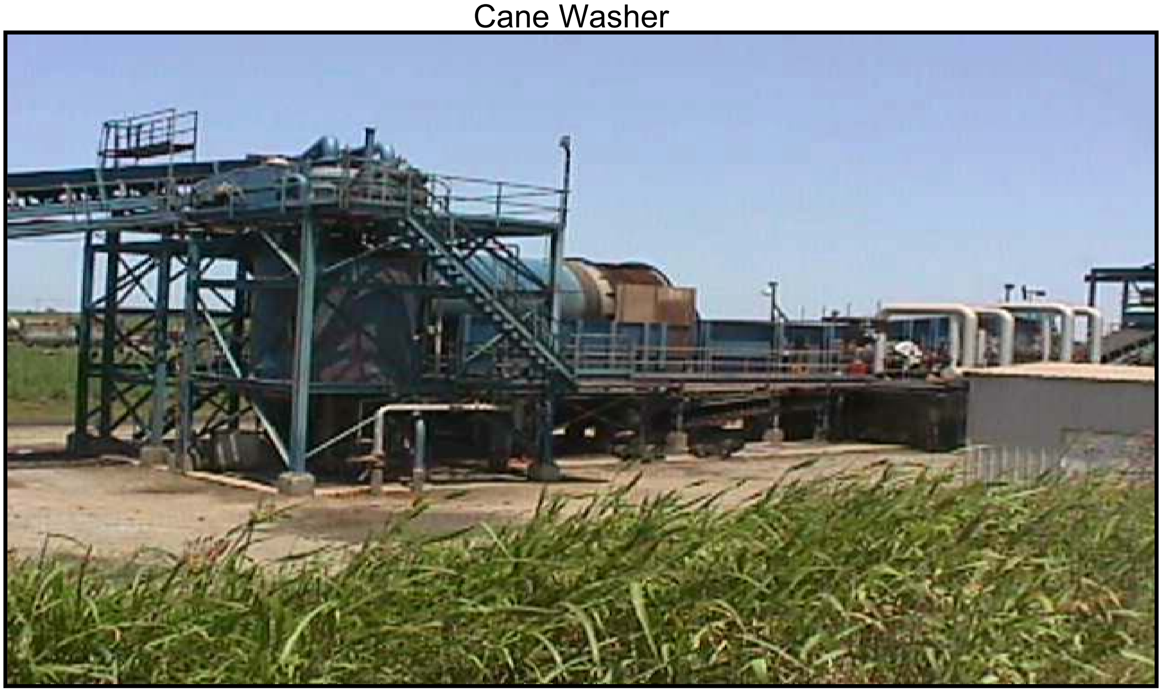


Figure 12
7’x7’ Interior of Washer

Figure 13
Shredder with Hammers

Figure 14
Bagasse Conveyed to Storage

2.2.2. Potato Harvest—A model for on-farm shelling

To accommodate farmers with grain bins for on-farm storage the potato harvest serves as a model. Potato storage sites are smaller and more dispersed than sugar cane mills. As nearby fields are harvested, trucks collect the potatoes from the "diggers" in the field and deliver to collection sites where they are quickly unloaded, washed and sorted by mobile equipment at a rate of 300 to 400 tons/hr—10 to 20 trucks/hr. Each truck usually makes a round trip in less than 1 hour.

The potato on-farm equipment is more complex than that needed for grain. The unloading, separating, sorting and storage equipment consists of a load accumulator, dirt/rock eliminator and sorter, dirt conveyor and two dirt dump trucks, screens for sizing and separating potatoes for immediate processing from those to be stored. Undersized potatoes are conveyed to a trailer and 2 to 3 semi-trucks make a long haul to the processor. Larger potatoes are conveyed to storage for later shipment.

The accumulator and the separator-grader are shown below, Figure 15. The accumulator, behind the truck and below right, can hold 50 tons and feed 5 to 7 tons/minute. The separator, below left, removes debris, sorts and grades.

Figure 15
Mobile Potato Harvesting Equipment

For corn, unloading the field collected material, separating the stover from the ear, shelling the ear and then trans-shipping the resulting stover is simpler, requiring less equipment and labor. The potato harvesting/operating crew totals about 35, including 12 to 18 “digger” and harvest truck operators, and 18 to 20 at the collection site—2 to unload trucks, 2 hauling dirt away, about 6 sorting, 3 to 4 hauling processor potatoes, 3 piling the potatoes in storage plus a leader and relief/maintenance person(s).

A one-pass corn harvesting crew would have the same number of field persons, but only 4 or 5 at the on-farm grain storage site—there would be no dirt to deal with, just unloading the trucks, monitoring the shelling and diverting the cobs and corn to storage, with 3 or 4 others hauling the stover to its collection site. Cobs store well in the open, without a need for cover. They can readily be transferred as needed after the harvest when resources are less constrained.

2.3. Collection Conclusions

One-pass collection appears feasible, collecting the grain and stover when the grain is ready for harvest and the stover is still wet. Collection must be done in a sustainable manner. High yielding, no-till fields with adequate moisture on slopes with less than 6% will be preferred. Cover crops may be needed in the crop rotation. Each field must be examined to determine the excess stover available for local conditions. Additional field measurements and practices will be developed to insure environmentally sound collection is practiced.

The collection cost depends heavily on equipment utilization. With no truck limitations, harvesters can travel 4.5 MPH, collecting 12 to 15 acres or more per day. With one-pass harvest and multiple collection points, grower net income AND the need for a

reliable, economic feedstock supply can likely be met. Initially, $30/ac net to the farmer and $30/dt delivered seem achievable for more than 1 million dt. In all cases, the out-of-pocket costs of the farmer are needed to be paid when incurred for wide participation.

An entirely new harvester design may not be needed, at least not until the next decade. The first biomass plant may be in operation by 2006 or 2007, with others forecasted to come on stream in 2008 to 2010. Meanwhile, collection can be adapted for the whole corn plant in several ways.

Modifying the Ear Corn Harvester Head appears simpler than modifying either the combine or the forage harvester. Based on present cost data, it also may offer the lowest whole crop collection cost. The ear harvester requires less power in the field than shelling with the combine or finely cutting with the forage harvester.

One farm wagon containing both ears and stalk billets reduces collection logistics. Many farmers prefer on-farm grain storage. The ear harvest reduces field loss and fits on-farm storage well. Shucking the husk and recovering the cob offers more "value-added" co-product opportunities. Cobs require little to no investment for stable storage. Husks may be combined with the stalks or fed to animals.

With the large legacy of combines and forage harvesters, many will likely be modified to accommodate the new needs while continuing to harvest soybeans, silage, hay and other crops. Increased equipment utilization and an earlier, possibly longer collection period can lower feedstock costs without shrinking margins.

The truck traffic to supply one processing site from the field— up to 200 trucks/hr in and out— is too disruptive to be acceptable in most locations. It is tolerated in sugar cane growing areas due to its long history. Using multiple collection sites for the stover reduces traffic congestion, can shorten the harvest window and reduces the weather risk. Locating stover collection sites next to existing grain elevators and adjacent to rail lines is also attractive and discussed further in 4. *Transportation*.

3. STORAGE

Wet storage of non-wood fibers, mostly bagasse, was first commercialized by E. A. Ritter in 1950 and has been practiced by the pulp and paper industry for more than 50 years (Atchison, 1971, 1972, 1985). A typical plant plot is shown below, Figure 16.

Figure 16
Wet Storage
Ledesma, Argentina

The bagasse storage is located in the lower right of the photo. The large flumes alongside the pile are used to transport the slurry. Rail service is adjacent, permitting easy unloading of bulk fiber shipments from other sugar mills.

3.1. Building the Wet Storage Pile

While there are some variations, most bagasse arrives at 50% moisture. It is slurried to 3% solids, pumped via an elevated flume or pipe and distributed on storage piles that range in size up to 200 meters x 300 meters with a height of 20 to 40 meters. The bagasse fibers become saturated at 80% moisture and excess liquid drains back to a collection basin (Figure 4) and is recirculated, bringing more material to storage. A pH of 3.5 to 4.0 is maintained in the pile under the anaerobic conditions as the residual sugars are converted to organic acids. The result is almost perfect preservation of the fiber and removal of 70% to 80% of the solubles in the bagasse after 90 days or more in storage.

The liquor insures compaction and complete wetting of the fiber. Figure 17 shows the discharge stream at the top of the pile. The flow is channeled by a crew on the pile,

diverting the flow where needed and directing the location of the discharge nozzles, Figure 18. In many locations, labor costs are low, reducing the degree of automation.

Figure 17
Constructing the Wet Storage Pile: 3% Slurry Discharge

Figure 18
Constructing the Wet Storage Pile: Work Crew Directing the Flow

The solution flows through the pile. The angle of repose is 45°, and the pile stabilizes at 80% moisture, Figure 19.1 and 19.2.

Figure 19.1
Fresh Storage Pile

Figure 19.2
Nine Month Storage

The liquid drains into the collection tank and is recirculated back, adding fresh bagasse to the pile. Vertical drainage through the pile is desired to obtain the best results—for high compaction and storage stability. To drain the large quantities of liquid, drainage channels covered with removable, perforated covers, are located every 15 to 20 meters across the pad.

The pile becomes so tightly compacted that no oxygen penetrates the material from about 1 meter from the surface inward. This results in negligible fiber loss, consistent feedstock and a high degree of preservation of the color and brightness. The outer layer is used for production of chemical pulp without loss of quality.

The liquor drops to about 4 pH as microbial action produces organic acids. To maintain this low pH during the pile construction, some locations add small amounts of molasses—one to two liters/dt. Where the bagasse has a residual sucrose content of 3% or more, no molasses is needed. The ideal conditions for feedstock preservation in large storage piles are 3.8 to 4.2 pH, 30 to 40° C and 75% to 80% moisture throughout.

Wet storage requires 40 to 60 gal/dt dilution water for 50% and 60% incoming feedstock moisture to saturate the fiber at 80% moisture. Over time, the pile drains to 75% moisture. Rain has no observable effect on storage. Before processing, a screw press lowers the moisture to 50%. The liquor is recycled back to the storage collection system, with a portion either land applied as a soil conditioner or treated in the wastewater plant.

3.2. Wet Storage Plant Results

Between 1920 and 1960 many skeptics expected the material to rot in a wet pile. When the method was a huge success, a number of studies were undertaken to better understand the wet storage process--where the material is completely saturated to its water holding capability. Studies of the two plants were particularly well documented--Ledesma, Argentina and Felixton, South Africa. The results are summarized below.

3.2.1. Ledesma, Argentina

To the surprise of many, one of the first published studies of the Ritter Process showed pulping bagasse stored from the previous season was superior to pulping fresh bagasse. As a result, bagasse is stored for 3 months or more before pulping, even during the sugar cane processing season when fresh bagasse is available (Moebius, 1966; Salaber and Maza, 1971).

The latter report describes plant trials at the Ledesma, Argentina mill in 1969 and 1970. Comparison of the fiber and pulp produced from stored bagasse versus fresh bagasse were carefully performed by the Research Laboratory working alongside plant personnel.

During the sugar cane processing season in 1969, 55,000 tons of fresh bagasse was processed directly in the pulp mill and 85,000 tons were stored and pulped in 1970. Processing conditions were the same for both. The stored bagasse had no measurable yield loss, either in storage or in processing. When compared to fresh bagasse the stored bagasse had the following advantages:

- Improved feedstock quality and consistency
- Better pulping results
- Better product quality of the final Bleached Pulp

The weight loss for the Ritter stored bagasse amounted to 10%— 7% loss of volatiles, water solubles during storage and 3% due to physical fiber losses, mainly from the outside layer of the pile and the material left to protect the concrete slab against the heavy equipment used to move the material from storage.

Removing the solubles improved the pulping results. Fewer chemicals were used in pulping, capacity increased and paper quality improved. While the same process was used for both, the following differences occurred:

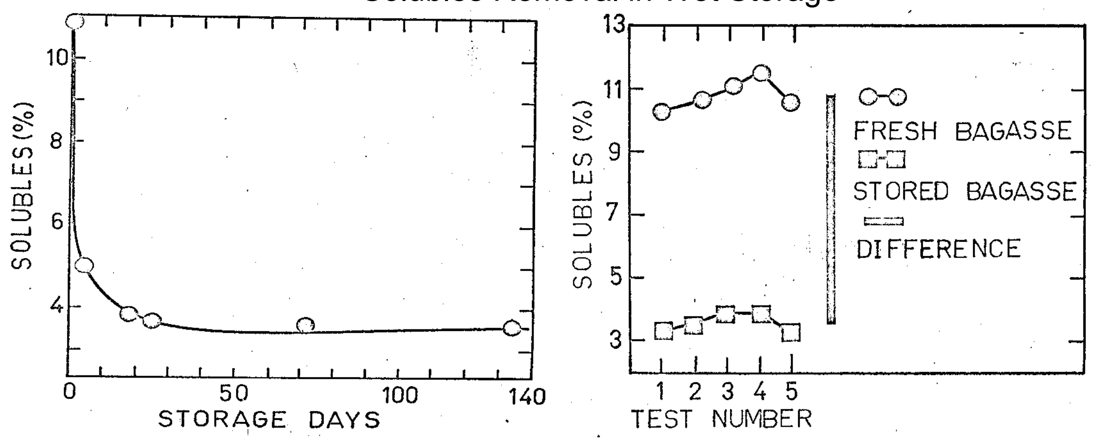
- The soda consumption for stored fibers was less
- Fresh fiber pulp contained uncooked fiber bundles even though it consumed more caustic soda
- Screening rejects for fresh pulp were 8% compared to 4% stored for pulp
- Fresh feedstock required more water and foamed in washing
- Caustic soda recovery was less with fresh bagasse due to foaming problems in the washing operation

The stored feedstock quality was better than fresh bagasse when comparing the following properties after three months:

- Water and alcohol-benzene solubles
- 1% caustic soda solubility
- Lignin content
- Pentosan content
- Holocellulose content

The percentage of cold and hot water and alcohol-benzene solubles decreased from 11% to 3.5% after 3 months. The lignin, pentosans and holocellulose increased proportionately to the decreases of the solubles in water, alcohol-benzene and 1% caustic soda. The absolute quantity of lignin, pentosans and holocellulose remained constant during the storage period. The loss in solubles during storage is shown in Figure 20, declining from 10% to 3% within weeks, and fresh bagasse having 7% less solubles for the 5 trials.

Figure 20
Solubles Removal in Wet Storage



The pentosans and holocellulose, which consists of the alpha-cellulose plus the hemicelluloses, continue to increase over a longer period, Figure 21 and 22.

Figure 21
Pentosan Change in Wet Storage

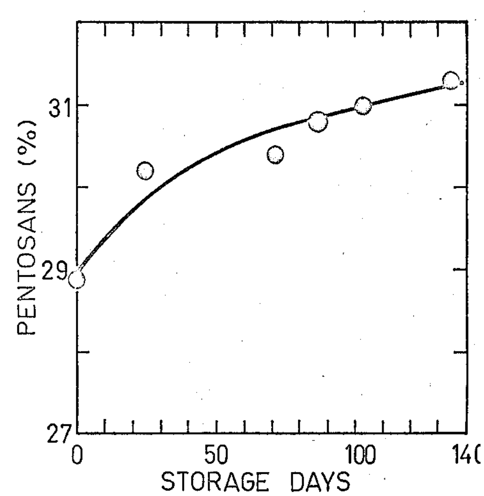
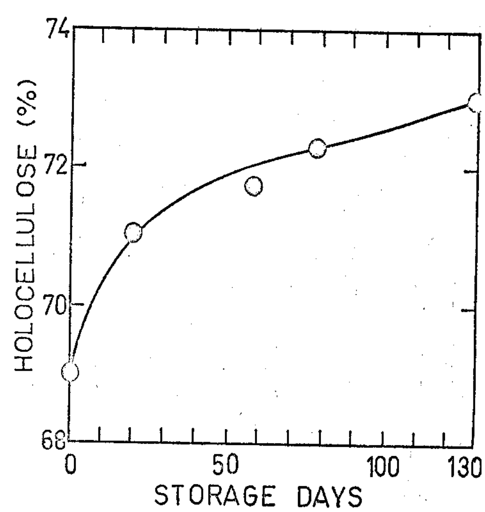


Figure 22
Holocellulose Change in Wet Storage



Stored bagasse produced higher quality pulp. It contained less foreign material and had higher freeness, Figure 23. Freeness is a measure of water drainage from the paper machine. It is a critical value for maintaining production rates for the

manufacture of paper sheets where fast water drainage is required for sheet formation and production of a consistent product.

The pulp also had a lower kappa number after storage, Figure 24. Normally the kappa number is directly related to the amount of lignin remaining. The reverse occurred in the stored material: it had a lower kappa value but a higher lignin content. The decline in the kappa number was attributed to other aliphatic double bonds, aldehyde groups and a-keto-carboxylic acid groups likely removed during storage.

Figure 23
Freeness Difference

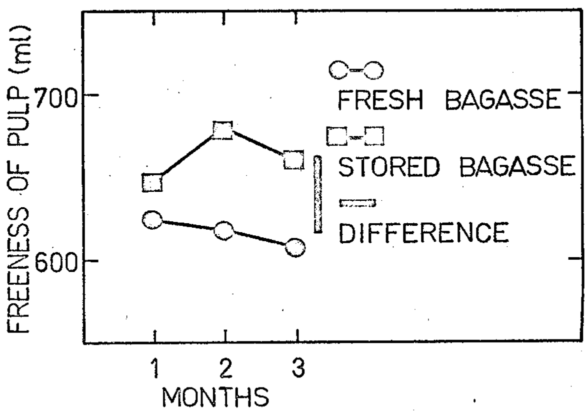
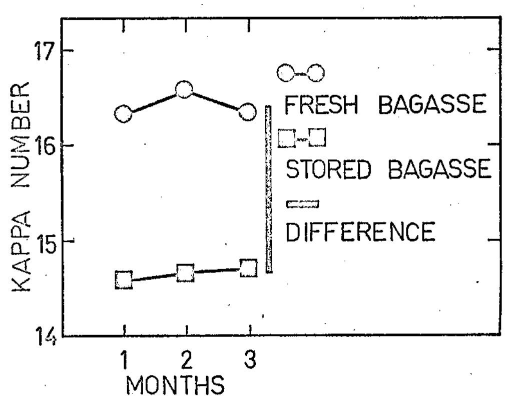


Figure 24
Kappa Number Comparison



3.2.2. Felixton, South Africa

Several years later wet bulk storage at the Mondi Board Mills-Felixton, South African conditions was investigated, adding to the understanding of the favorable results from the Ritter Process (Bruin et. al., 1974). Three different liquid media were used:

1. The Ritter Process, the same process studied in Ledesma
2. Backwater, water generated downstream of the digester, a composite of strongly alkaline streams--9.5 to 10 pH
3. Mineral and Organic Acid, filtered river water with sulfuric acid and formic acid added adjust to 4.3 to 4.5 pH

Three feedstock piles, one for each media, were built to supply enough material for nine 2-day plant pulping trials. Each media test series used bagasse after 2 weeks, 8 weeks and 20 weeks of storage.

The pulp produced from the bagasse stored according to the Ritter treatment protocol was found to be superior in physical strength, freeness and chemical consumption when compared to the Backwater and Mineral/Organic acid treated bagasse. Interim storage losses for the Ritter method are below:

Storage period	Weight loss (%)
2 weeks	1.7
8 weeks	4.3
20 weeks	5.3

Overall, about 10% loss occurred, mostly solubles, the same as previously reported (Salaber and Maza, 1971). Storage loss figures for the Backwater and Organic acid treatments were not obtained.

When using Backwater media, a rapid drop in pH ensued. To raise the pH, two batch additions of caustic soda were made to the circulating liquid. This treatment had no lasting effect, returning to 5.1-5.4 pH during the pile construction (100 hours), then dropping to 5.2 pH in 2 weeks, 5.0 after 8 weeks and about 4.9 in 20 weeks.

Bacterial counts revealed all three piles contained anaerobic microbes. No cellulose digesting or lactic acid producing microbes were found, nor was lactic acid detected. Acetic, propionic and butyric acids were found in the Ritter stored pile; acetic, propionic, butyric and valeric acids were found in the Backwater pile. The Mineral/Organic Acid pile was not tested for acetic acid but propionic and butyric acids were present.

3.2.3. Other Studies

A wet bulk storage system at the bleached bagasse pulp mill in Pingtung, Taiwan provides a detailed plot layout. Rail delivered bulk bagasse from other mills (Wang and Tao, 1978). Less detailed information is available describing wet storage experience in Mexico, Venezuela, Iran, Taiwan and Colombia are listed in References.

In the 1960's a series of experiments were carried out in Louisiana to replace bale storage. Since a dry feedstock was preferred, the investigators spoiled a lot of bagasse before moving to a system that increased the moisture above 60%.

They settled on a process that sprays water on the pile as 50% solids are conveyed to the pile. The material is stored on graded soil. The pile is ditched and drain water is channeled to the wastewater treatment plant (Bernhardt, 1968; Guidry,1973).

3.3. Removing the Pile

The piles readily support heavy equipment. A large pile of wet bagasse shows a road in the foreground made by the adjacent front-end loader, Figure 25. Depending on local practice, the stored material may be simply shoved down the side and re-slurried for transfer to the pulping process. Others use conveyors. Some use rail and trucks for inter-plant delivery. In the case below, the road enabled trucks to reach the top and be loaded for use by an adjacent process.

Figure 25
Bagasse Storage Transfer

3.4. Storage Comparison

A comparison of dry bale and wet bulk storage shows there are significant advantages for the wet method in most categories tabulated in Table 10.

Table 10
Dry and Wet Storage Comparison

Parameter	Dry (bales)	Wet storage (Ritter method)
Dry Density, lbs/ft3	7 to 10	12 to 14
Storage area	10x	1x
Storage Loss	>10%	<5%
Foreign matter & soil nutrients	High	Low
Non-volatile solubles removal	Process Residue	Storage Liquor
Weather Risk	Rain	Extreme Cold
Fire hazard	High	None
Investment	Low to High	Medium to High
Storage quantity	Small, mostly farm use	Large, bagasse for pulp

3.4.1. Density

The dry density of bales is about half that of wet stored material, ranging between 7 dry lbs/ft^3 ($112kg/m^3$) for round bales to 10 dry lbs/ft^3 ($160\ kg/m^3$) for square bales. Wet storage density depends on the stack height, with 40 meters achieving 12.5 dry lbs/ft^3 ($200\ kg/m^3$) average pile density (Moebius, 1975; Bates, 1980). Values as high as 14 dry lbs/ft^3 ($225\ kg/m^3$) have been measured near the base of piles (Bruin et. al., 1974).

3.4.2. Storage Area

Square bales require about 10x the wet storage space due to bale stacking limits, access corridors and a measure of fire protection. The total area required for 1 million dry tons is about 500 acres for square bales. With wet storage, a 333,000 dt pile requires 15 acres. For 1 million dt storage, just 3 piles or about 50 acres is needed. The equivalent land rent is not usually included in the feedstock cost.

Square bales, 10 dry lbs/ft^3, can be stacked about 300 lbs/ft^2 or 30 feet high before the weight begins to compress the lower bales, causing the stack to shift in storage and possibly fall. Following insurance underwriting guidelines, bales are limited to 4,000 tons/pile with a minimum of 30 meters distance between piles. Round bales require about 40% more storage area, 170 to 200 dry lbs/ft^2. For Stakhand piles and cotton modules, even more area is needed.

3.4.3. Storage Loss

Bales are adversely affected by wet weather and without shelter can decompose and break apart (Figures 2.2 and 2.3). For 6' dia x 5' bales, 30% of the mass is in the outer 4 inches and 25% weight loss can easily occur in one season. Stored inside barns, both round and square bales had 14% weight loss over 10 months in Eastern Canada (Billy, 2000). The overall composition remained nearly the same.

For wet storage, the major losses are the 5% to 8% solubles removed during storage. Typical cellulose and hemicellulose losses reported by the pulp and paper industry are 1% to 3% (Moebius, 1965; Salabar and Maza, 1971; Atchison, 1972). Surface loss is dependent on the total surface exposed relative to the stored tons. The higher the pile, the smaller is the surface exposure and the surface loss. While there may be aesthetic limits, wet storage piles can go beyond the present size of 40 meters.

3.4.4. Foreign Matter and Solubles

Bales harbor foreign material that can be deleterious during storage and processing. Soil nutrients, especially P and K, are removed with the bale, depleting the soil. While there is considerable variation in the composition (Hames, et. al., 2002), their average value is \$3.20/dt (Glassner et. al. 1998). For sustainable harvest, nutrients contained in the stover must be replaced.

Wet storage has proven to remove dirt, foreign matter and solubles over time. Removing the nutrients during storage, returning them to the fields is much preferable in lieu of processing the bales and disposing of the process ash. Less solubles in the wet, stored feedstock with the absolute values of holocellulose and pentosans unchanged increases the plant capacity up to the distillation step: 7%

removal opens up 7% more pretreatment, hydrolysis and fermentation capacity. More distillation is required for the increased load.
The process and economic impact is significant. A nominal 60 million gallon plant increases 2 million gallons, to 62 million gallons annually. NREL's Aspen model indicates a cost decrease of $0.04/gallon, $2.4 million annually. The improvement assumes half the solubles are removed in storage and an additional 3.5% feedstock is processed.

3.4.5. Disposal of non-volatile solubles

Crop residues contain up to 12% solubles, including valuable soil nutrients. In dry climates, farmers often run the irrigation system before baling to wash some of the solubles into the field. Unless removed, they are processed, becoming part of the process residues. Presently it is uncertain if the process residue must be landfilled or may be used as a soil conditioner. Either route is expensive. Annual landfill cost is $1.6 million for a 2,000 dt/day plant at a nominal $20/dt.

In wet storage, most of the non-volatile solubles are removed before processing. Excess liquor is high in nutrients and can more likely be returned to the soil, free of process ash. In either case, transportation can be a significant cost factor. More investigation is needed to determine the cost and disposition of each.

3.4.6. Weather Risk

While wet weather is the bane of baling, jeopardizing residue collection, once baled, they must be protected to avoid major loss. Roofed shelters are generally preferred over tarps. Square bales must be covered or risk extensive damage, including fire. Round bales may be mesh wrapped, but wrap disposal present another cost.

Sugar cane is a warm weather, tropical crop, how will storage endure extreme cold? Feedlots typically ensile forage crops like corn and hay, targeting moisture level of 65% for this reason in the northern parts of US. Local ranchers report some icing problems, but those questioned said front-end loaders work well in moving the semi frozen material. Perhaps the microbial activity at the exposed surface helps.

In any event, additional proof of concept is required for extreme cold. While the size of the pile is expected to be a factor, will the insulation provided by surface fiber prevent the pile from turning into a mountain of ice? Additional investigation is needed for colder climes and other feedstocks like stover and cereal straw.

3.4.7. Fire Hazard

As shown (Figure 2.4), bale fires, once started, result in a total loss. They burn slowly, with much smoke, and can last weeks. Nearby areas often are obscured and at a minimum inconvenienced. At worst, roads may be closed and neighborhoods evacuated. Wet storage piles, 75 to 80% moisture, are not flammable.

3.4.8. Industry Proven—for bagasse wet storage.

Bales are largely for on-farm use and have been used for small industrial applications, mostly for particleboard. Large applications that rely on bales have historically encountered problems including cost, quality, storage deterioration, fires and adequate supply (Lengel, 2000). These same problems encouraged the non-wood fiber pulpers to move to wet storage more than 50 years ago with much proven and well-documented success. While stover and straw are expected to perform in a similar manner, validation is required

3.4.9. Investment Required

Investment can vary widely for both types of storage. An uncovered stack of round bales on the ground has negligible investment, Figure 3. Sheltered bale storage investment similar to Figure 2 can be high, depending on the degree of automation.

Bale storage systems were recently estimated for rice straw (Huisman et. al, 2002). Short term, tarps were favored at a cost of \$7 to \$10/dt. Longer term, pole barns are favored, costing 50% less with the upfront investment.

Wet storage investment cost needs to be investigated and evaluated as part of the supply chain—from one-pass harvest and the modified cropping practices through lowering the amount of process residue and disposition cost of the residue and storage liquors. Transport to the nearest collection center, the collection centers with truck unloading and rail loading facilities, circulation basins, flumes, pipes and other equipment would be included, including the disposition of the nutrient containing liquor.

At the plant, the bale unloading, interim storage and handling system designed for NREL's model has a \$12.9 million capital cost, \$2.94/dt. The operating cost is \$2.62/dt based on 12 operators 24/7 to handle the bales, adding a total of \$5.56/dt to the feedstock cost (Harris, 2000: Aden et. al., 2002; Wallace, 2003). Rail car unloading is automatic, and no additional labor is expected other than the train crew included in the rail cost in *4. Transportation*.

3.5. Storage Conclusions

Wet storage appears to offer significant economic and practical advantages over bales, at least in warmer climes. Process economics are improved with a wet, more consistent feedstock with less solubles and ash. If the solubles extracted in storage can easily recycle nutrients removed with the residue to the field, another advantage is gained over bales.

Large-scale field trials similar to existing bagasse piles, up to 40 m x 40 m x 20 m high, are recommended to validate the wet storage process for stover. Smaller piles may be attempted, but the results are likely to be skewed due to their size.

Smaller piles require less circulation time to construct, have greater surface area exposed and may be less dense, impacting the degree of microbial activity. Some questions that arise include the following:

- Will less circulation affect the solubles removed from the feedstock?
- How does the larger mass to surface area ratio impact the loss of volatiles and cellulosic feedstock?
- Will less circulation and less height result in adequate compression to minimize destructive microbial activity?
- Can bench tests and/or several smaller piles with increasing heights, 2, 4, 8 and 10 meters provide the needed information?

The high storage moisture, 75% to 80%, raises freezing concerns during extended extreme cold periods. A small pile can turn into a block of ice more readily. The high moisture also limits transport options. Passing the feedstock through a screw press can readily lower the moisture to 50% for transport and processing.

The type of storage affects the processing cost. Field storage cost of bales is now assumed in the delivered bale price, and capital for bale handling at the processing plant is estimated to cost $10 to $15 million (Harris Group, 2000). Most of this equipment is not required when wet material is received. A capital investment and operating cost estimate is needed for the supply chain systems.

4. Transportation

Wet biomass is extensively transported by the following industries:

- Forest Products—wood chips
- Breweries—brewers grains
- Distilleries and Dry Mill Ethanol Plants—distillers grains
- Corn Wet Millers—corn gluten feed
- Sugar CaneMills--bagasse

The moisture varies between 40 to 60%. Transit time must be short, as aerobic microbial activity in shipment and storage at the customer site can damage the product. To avoid drying costs, the corn wet milling industry, breweries, distilleries and corn dry millers truck wet grains to regional feedlots and dairy herds, sharing the

net savings between higher product freight and lower drying cost with the customer (Perrin and Klopfenstein, 2000).

Trucks have been favored over rail for wet animal feed—brewers grains, distillers grains and corn gluten feed—in most cases due to the relatively low quantity needed. Most customers require truckload quantities of feed, making inventory turnover, freight rates and slow delivery unfavorable for small numbers of rail car quantities.

The forest products and sugar cane industries have mostly used rail. Unit trains supply more than 1,000 dt/day of 50% moisture wood chips or wet bagasse for pulp mills.

With the trend to larger cattle and dairy herds, along with increased feed drying cost and the economy and speed of unit trains, some animal feed suppliers are also moving from truck to rail. One supplier has begun unit train shipments of 40% moisture corn gluten feed from Iowa to Texas (Fisher, 2002).

4.1. Corn Stover Transport

Transporting wet stover via trucks to supply a 2,000 dt /day for processing 350 days per years was recognized as a problem early on. Alternate possibilities--pipelines, dirigibles and rail, were discussed in a series of colloquies with those in position to influence the future direction of the industry in 1999 (Hettenhaus et. al., 2000).

4.1.1. Pipelines

Pipelines are the least intrusive mode to transfer the material and would likely have the lowest operating cost. The material could be transferred from collection sites to the processing plant as needed. Since the slurry would be low in solids, two lines may be required, one to transfer the solids and the other returning the liquid.

Easements could likely be obtained since there is local self-interest—to sell stover and minimize the truck traffic. Engineering and construction are well understood. Since investment in the pipeline is required, it is likely this may evolve after the process is proven.

4.1.2. Dirigibles—Will They Fly?

During the colloquies, dirigibles were suggested as a transport mode to reduce truck traffic. A recent attempt to commercialize airships, Appendix A, indicates they are more likely to be used for transporting heavy equipment—oversize generators, pre-assembled plant modules, field hospitals for remote humanitarian needs—long distances.

Investors—Siemens, ABB and others—see the airship as a “floating crane,” being able to set in place their fully assembled equipments such as turbines and generators. Now shipment size restrictions often force this equipment to be shipped in pieces.

One m^3 of helium supports one kg of mass. Increasing the airship structure increases the payload—up to a certain point where structure load limits are reached. For the dirigible, the payload is 160 metric tons with a total weight of 550 metric tons. The structure for both is the same: simply a keel with the gas enclosed by the fiber above. There is no superstructure.

For 2,000 dt/day, 14 loads would be required for bales, 25 for wet material. The cargo space can carry biomass with a density as low as 5 dry lbs/ft3 and still have a full load. Using 50 MPH and 30 minutes for both loading and unloading, 1-160 metric ton load, the travel time is only 1.2 hrs for bales—0.6 hr out and 0.6 hr back—gives an ‘average’ harvest radius of 30 miles. Wet material is about half, so collection points require a high density, or more units are required.

There is the major obstacle of $50 million for each CargoLifter™. To fill the airship with helium is an additional $2.5 million. Using 20% of $50 million as recovered cost, $10 million per year, is $27/dt for freight. While the first flight was planned in 2003, the company is insolvent, attempting to reorganize its financing. Cost improvement has to be significant for this project to fly!

4.1.3. Rail

Rail appears to be the preferred mode over pipelines and certainly dirigibles. A likely scenario for transporting the wet material from storage is locating the collection sites adjacent to rail facilities. If the site is also next to a grain elevator, ears may be shelled on site and no trans-shipment of the stover is needed.

For transporting wet stover from the collection sites to the processing plant, wood chip cars appear well suited. Their large size is designed to haul low-density products, Figure 26. They are in wide use now, capable of carrying 100 tons or more with a capacity up to 8,000 ft^3. A manufacturer's typical specification is given in Appendix B. An 8,000 ft^3 car reaches both cargo volume and weight limits at 70% moisture, Table 11.

Figure 26
Loaded Wood Chip Gondola Car

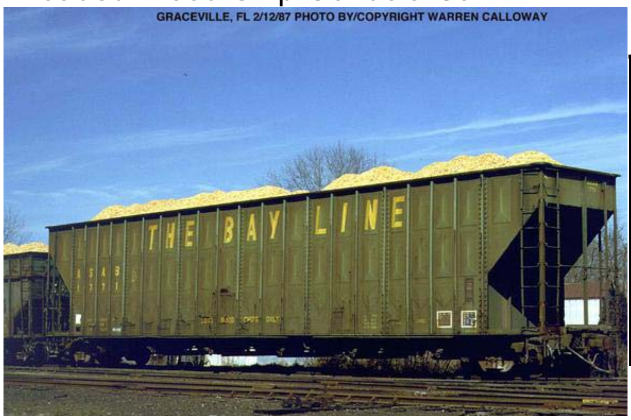


Photo used with permission.

Table 11
Gondola Stover Capacity
50% and 70% Moisture
8,000 cubic feet, 100 ton limit

Moisture	Density lbs/ft^3	Tons	Dry Tons
50%	15	60	30
70%	25	100	30

The stover bulk density is expected to be about 15 lbs/ft^3 at 50% moisture, and 25 lbs/ft^3 at 70%. For 50% moisture, the volume capacity is reached first. Both deliver 30 dt/car.

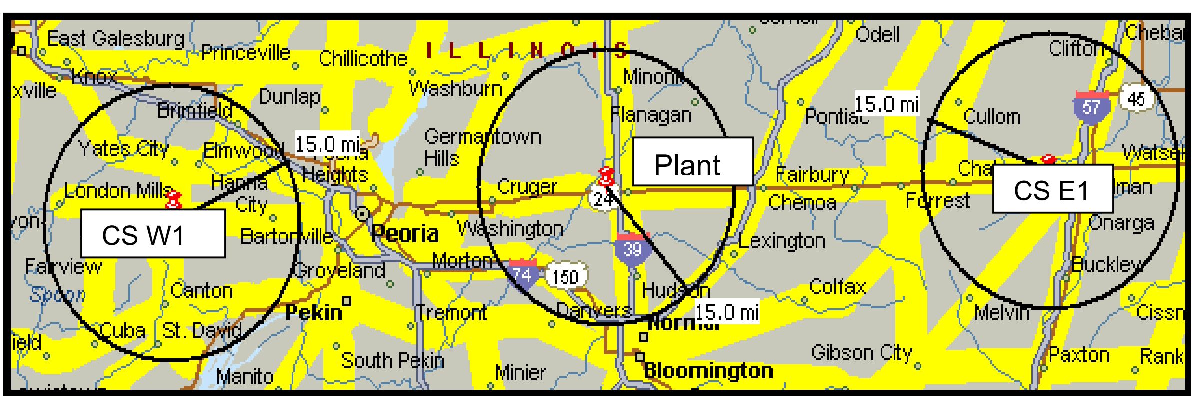
For the initial plant, locating three collection sites to supply the plant, one adjacent to the plant and two adjacent to a rail line within 50 to 60 miles of the plant offers the following advantages:

- Low transport cost
- Reduced traffic
- Clear route to expand plant capacity

Low Transport Cost

An example site is shown in Figure 27 for Illinois. The plant site is located near El Paso, IL. A rail line links the plant with a collection site in Chatsworth to the East, CS E1 and a western collection site in Farmington. The total distance is about 100 miles, avoiding congestion through Peoria. As the plant feedstock needs grow, additional sites can link to the plant via rail.

Figure 27
Rail Linked Illinois Plant Site



Assuming 3 dt/ac is removed from 40% of the land, a 15 mile collection radius for each is estimated to supply 1.5 million dt of stover for $5.10 (Table 5, page 14). With up to 15% soluble, volatile and other losses, about 0.4 million dt can be supplied from each site during the year. A seasonal carry-over inventory can be managed after the first year, similar to bagasse inventory management where stable storage for two seasons is commonly practiced.

The estimated rail cost is estimated at $2.5 million annually for 700,000 dt transported from the two collection sites, 350,000 dt from E1 and the same amount from W1 at a cost of about $3.50/dt. The costs are summarized in Table 12.

Table 12
Estimated Rail Transport Cost
30 MPH farm rail line

	Units	Annual $(000)	
Rail Track, Miles		100 mi	200 mi
Cars	200	$ 600	$ 600
Engines	2	$ 180	$ 180
Fuel	110 gal/hr	$ 590	$ 1,780
Crew	4	$ 960	$ 2,880
Track Lease	$100/mile/month	$ 120	$ 240
Annual cost		*$ 2,460*	*$ 5,680*
Cargo	dt annually,000	700	2,000
$/dt		$ 3.50	$2.80
Car utilization	8,000 hrs/yr	25%	90%

Operating cost is mostly fuel, and rail generally requires less than 5% of truck power: 20 HP/ton for trucks vs 0.5 HP/ton rail.

Rail utilization is just 25% with two 50-car unit trains delivered each day, 4 days per week. The total round-trip time, 30 MPH average, is less than 2 hours between the plant and each collection site. The gondola cars lease between $200 and $300/month or $600,000 annually for 200 cars. Two engines with a 4 person crew and fuel add $1.8 million. Only 100 miles of track are required initially. An annual lease of $100/mile/month or $120,000 is assumed.

The limit for the equipment in Table 12 is about 2 million dt feedstock. Adding two collection sites, two more crews and doubling the leased track lowers the estimated transport cost to $2.80/dt while increasing equipment utilization to 90%. In this case, the plant is supplied with 200 cars/day every day, nearly 6,000 dt. With 400,000 dt, the plant site holds a 70 day supply, ample for transport contingencies.

<u>Reduced traffic</u>

As indicated earlier in *2. Collection,* truck traffic problems increase with increased plant size while gondola shipments are more manageable. Assuming 50 car unit trains

traveling at 30 MPH (off the main line), about 1.5 minutes is required for the train to pass a road crossing. In contrast, when the truck delivery is limited to just 10 hours each day and 5 days per week, the truck traffic increases by 3.

For bales, most propose off-site storage with regular feedstock deliveries made during the year. If one-third of the plant needs are supplied by feedstock on site, more than 200 truck deliveries are still needed during a 10 hour day or 40/hour in and out, Table 13.

Table 13 Plant Feedstock Requirements Rail and Truck Traffic Volume, units/day						
Plant, dt (000)		700	1,000	2,000	4,000	6,000
Mode	*Moisture*	*Units/day* (60 hr/week truck delivery)				
Gondolas	50 to 70%	44	64	130	250	380
Trucks	50%	67 (200)	95 (280)	190 (570)	380	570
Trucks	70%	111 (333)	160 (480)	320 (1000)	640	1,000
Trucks[1]	Bales	41 (123)	60 (180)	120 (360)	240	360

[1]Bales are based on 20 tons/load, 15% moisture

Expanded Capacity

An intrinsic problem for biorefineries is 'economy of scale' compared to petroleum refineries. Petroleum refineries average more than 100,000 barrels (4.2 million gallons) per day. Table 14 compares the feedstock needed to for a biorefinery to approach a petroleum refinery for ethanol yields ranging between 65 and 95% of cellulosic sugars.

Table 14 Biorefinery Feedstock Requirements Petroleum Refinery Comparison						
Plant dt (000)	700	2,000	4,000	6,000	12,000	15,000
Yield Gal/dt	Ethanol Production Barrels per Day					
80	3,800	10,900	21,800	32,700	65,300	81,600
100	4,800	13,600	27,200	40,800	81,600	102,000
120	5,700	16,300	32,700	49,000	98,000	122,400

The logistics of bringing dry biomass to a conversion plant limit the feedstock supply (Aden et. al., 2002; A.D. Little, 2000; Shell, 2002). Using an analysis of stover availability (Walsh et. al., 2000) and plant size, the optimum scenario using ORIBUS located 35-700,000 dt plants across Iowa (Sheehan, 2002). Their modeling shows conversion costs drop 30%, about $0.20/gal EtOH, for a 4 million dt plant--but are offset by feedstock cost and availability.

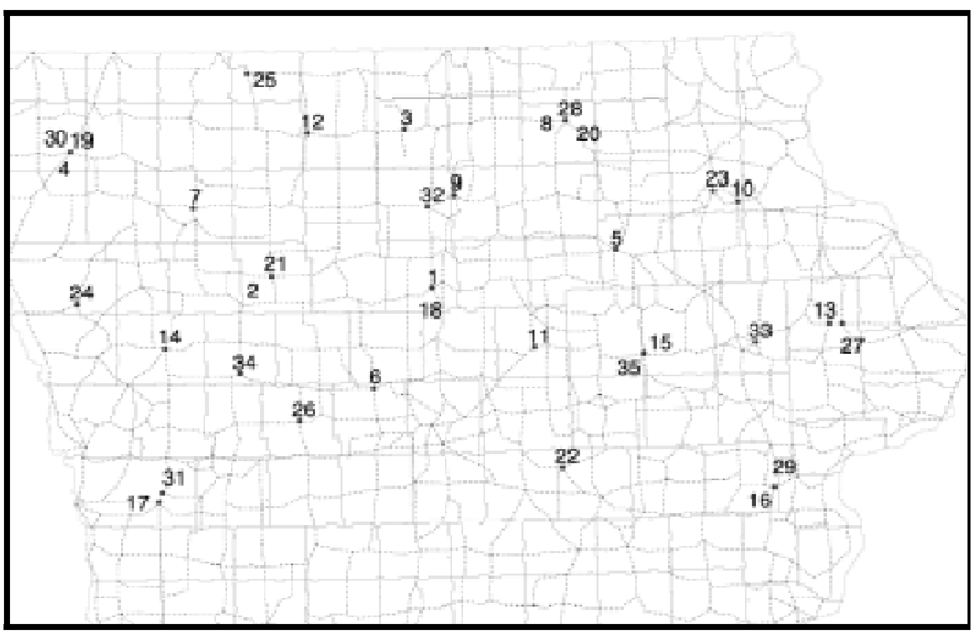
Rail shipments can improve the supply and the biorefinery economics. With multiple collection points on rail sidings, the collection area for a plant can be extended from a 50 mile radius, about 8,000 sq miles to more than 30,000 sq miles. Seasonal fertilizer, wheat and other Ag product shipments constitute most of the traffic.

Maximum load per car is usually 125 tons, 100 tons net, to accommodate grain shipments. The cost for rail transit was estimated to be less than \$10/dt for transporting feedstock several hundred miles. The cost to move a car 100 to 300 miles is \$150 to \$250 with little regard to weight (Roof, 2002).

With 25 lbs/ft^3 density and 50% moisture, stover transport costs are \$3.00 to \$5.00/dt over this distance. Compacting the car with vibrators or “Stakhand” type devices while loading—as long as the cargo can be readily unloaded and processed—can insure low delivery cost from distant collection sites. The dense car has an additional benefit of inhibiting microbial activity during transit.

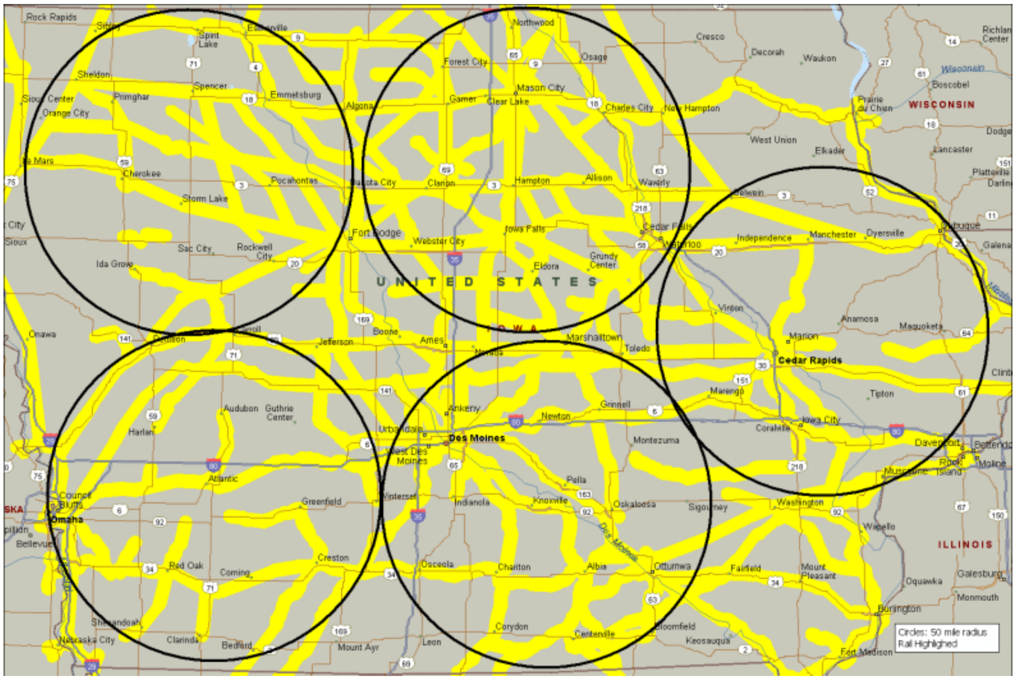
In areas where much stover is available, the traffic patterns likely favor rail to supply feedstock for plant expansions over constructing new plants. For example, in Iowa the 35 plants projected by the ORIBUS results Figure 28.1 (Adens et. al., 2002) may be replaced by 5 or fewer plants with more than 5 million dt capacity, simplifying logistics and lowering cost using the extensive rail system shown in Figure 28.2. Logically, rail density is greatest in areas of highest crop production.

Figure 28.1
Location of 35- 2000 dt/day Ethanol Plants in Iowa
ORIBUS GIS Model Results



From Adens et. al., 2002

Figure 28.2
Iowa Rail System
Circles w/50 mile radius



4.2. Transport Conclusion

The large existing infrastructure for roads and rail make investment in new pipelines unlikely. For short distances, less than 15 miles, trucks over the road can readily supply up to 1,000 dt/day feedstock of either wet or dry material economically without disrupting traffic.

Adapting wet storage and rail transport practices now used for bagasse to stover can increase the collection area and the economic plant size. Plant expansion can occur by locating additional collection sites for rail shipment 50 to 200 to 300 miles from the plant.

Transport cost and the environmental impact is less due to the efficiency of rail vs truck hauling for longer distances. Disruption of traffic is small when compared to trucking. Investment in plant staff and facilities is reduced by unloading rail cars directly into the plant for processing.

CONCLUSIONS

- Biorefineries with wet processes are most likely to use feedstock supplied by unit trains from wet storage collection sites well beyond the present 50 mile radius collection limit for bales
- Existing combines, forage and ear corn harvesters can be modified for one-pass harvest of grain and stover
- Collection risk and cost is less for wet processes as stover is collected when grain is ready—no drying or densification is needed

RECOMMENDATIONS

- Develop and apply guidelines for sustainable stover removal and proceed to validate them in local areas with large amounts of excess material
- Wet storage, 75 to 85% moisture is well proven for bagasse, but stover needs validation in a range of temperatures—including the effect of extreme cold
- Determine the impact of wet storage on processing ease
- A revised capital investment and operating cost estimate is needed for biorefineries using wet storage systems—from one-pass harvest and the modified cropping practices through lowering the amount of process residue and disposition cost of the residue and storage liquors
- The Life Cycle Analysis for stover to E85 fuels is needed to assess the impact of efficiencies achieved with one-pass harvest, changes in cropping practice, rail vs truck hauling, nutrient return from collection sites, and plant processing factors
- Prepare a “Big Picture” plan for implementation with wide participation of members in the supply chain

ACKNOWLEDGEMENTS

Our thanks to Tommy Duhe, Richard Hess, Dan Towery, Kelly Ibsen, Jim McMillan, Doug Ahrens, Rodney Roof, Anthony Turhollow and Jim McMillan for their suggestions and comments in the preparation of the report.

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Appendix A
Dirigibles--Will They Fly?

CargoLifter™, a German dirigible company was successful in funding a recent attempt to commercialize airships. Due to high costs it is more likely they will be used for transporting heavy equipment—oversize generators, pre-assembled plant modules, field hospitals for remote humanitarian needs--long distances. Some parameters for the German plan:

- Payload 160 metric tons, 176 short tons
- Range, 6000 miles
- Speed, 60 MPH
- Estimated unit production cost 50 million Euros (currently $49 million)
- Trans-ocean cost per load, $0.5 million, delivered point to point in 3 days (Current door to door for ocean freight is 25 days AND highway dimensions size of shipment.)
- First flight planned in 2003 BUT requires more financing
- ABB and Siemens are investors, seeing the "floating crane" being able to set in place their fully assembled equipments such as turbines and generators.

It is BIG! The Goodyear blimp is less that 1/10 the size of the dirigible.

- German Dirigible 852 feet long x 210 feet high x 210 feet long
- Goodyear Blimp 192 feet long x 57 feet high x 54 feet long
- Zeppelin 776 x 110 x 100 feet

Payload: Basically 1 cubic meter of helium supports 1 kg of mass. Increasing the airship structure increases the payload—up to a certain point where structure load limits are reached The payload for the Goodyear blimp is 5 passengers or less than 1 ton. For the dirigible, the payload is 160 metric tons with a total weight of 550 metric tons. The structure for both is the same: simply a keel with the gas enclosed by the fiber above. There is no superstructure per se. The crew quarters, engines and cargo are incorporated in the keel.

For comparison, the zeppelin that burned had a capacity of 50 passengers, 25 tons. It was about 1/2 the size BUT had hydrogen (10% more lift) and an aluminum superstructure. Size of the cargo hold is 36 std container trailers, stacked 3 high, 3 across and 4 long, equivalent to 50 m X 7 m by 7 m. The cargo space can carry biomass with a density as low as 5 dry lbs/ft3 and still have a full load. Square Bales are typically 9 to 10 lbs /ft3.

Flight Performance: Maintaining constant altitude is a challenge. The temperature impact on the gas causes significant buoyancy changes. Simply going behind a cloud can change the lift by 5 to 10 tons or more. Water is used for ballast. Loading and unloading the payload weight requires about 40,000 gallons to be transferred to maintain altitude.

Feedstock delivery analysis: Assume 1,000 dry tons feedstock per day with a yield of 90 gal EtOH, about a 30 million gallon plant. Ignore weather difficulties for flight time. For a 1,000 dry ton per day delivery schedule, 7 loads are required using 50 MPH and 1 hour for both loading and unloading (30 minutes each). It could be shorter, raising/lowering 4-40 metric ton loads, vs 2-80 metric ton loads or just 1-160 metric ton load), the travel time is only 2.4 hrs—1.2 hr out and 1.2 hr back—gives an 'average' harvest radius of 60 miles. There is the major obstacle of $50 million cost per unit. Helium cost is $2.5 million to fill the airship. Using 20% of $50 million as recovered cost, $10 million per year, is $27/dry ton cost for freight. Cost improvement has to be significant for the project to fly!

Appendix B
Wood Chip Car Specifications

A typical rotary dump gondola car is described below by its manufacturer, Johnstown America Corporation. The car serves woodchip and other low-density product markets.

Specifications and Dimensions			
Woodchip BethGon® Car			
Length	(feet & inch)	Capacity	(cubic feet)
Inside	67' 5"	Level	8,160
Over Strikers	69' 5"	Weight	(pounds)
Over Pulling Face	72' 0-1/2"	Gross Rail Load	286,000
Truck Centers	58' 6"	Light Weight	73,100
		Load Limit	212,900
Width	(feet & inch)	Center of Gravity	(inches)
Extreme (Side Sills)	9' 9-29/32"	Level	99.6"
Inside	9' 1-1/4"		
Height	(feet & inch)		
Extreme	16' 3"		
Rail to Top Chord	16' 2"		

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 2004	3. REPORT TYPE AND DATES COVERED Subcontract Report

4. TITLE AND SUBTITLE
Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting

5. FUNDING NUMBERS
ACO-1-31042-01

6. AUTHOR(S)
J. E. Atchison and J. R. Hettenhaus

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Atchison Consultants, Inc., and
Chief Executive Assistance, Inc., Charlotte, North Carolina

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/SR-510-33893

11. SUPPLEMENTARY NOTES
NREL Technical Monitor: S.R. Thomas

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Investigation of innovative methods for collecting, handling, storing, and transporting corn stover for potential use for production of cellulosic ethanol.

14. SUBJECT TERMS
biofuels; ethanol; fuels; economic assessment; technical assessment; technoeconomic assessment; biomass; collection; transport; storage; handling; stover;

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL